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A PALEOECOLOGICAL STUDY OF THE ANTE CREEK REEF,  
MIDDLE TO LATE DEVONIAN IN AGE,  
WEST CENTRAL ALBERTA

by



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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES  
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE  
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DEPARTMENT OF GEOLOGY

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Paleoecological Study of the Ante Creek Reef, Middle to Late Devonian in Age, West Central Alberta", submitted by Barry David Corneil, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

Thesis  
1969  
31



## ABSTRACT

The Ante Creek Reef Complex is a reef-fringed carbonate bank of low topographic relief located on the subsurface Beaverhill Lake carbonate platform 175 air miles northwest of Edmonton.

A dense dark brown biostrome (Dark Brown unit) provides the platform on which the light brown porous bioherm or true reef (Light Brown unit) rests. The biostrome and the overlying bioherm constitute the Swan Hills Formation of Middle to Late Devonian age. Stratigraphically, the Swan Hills Formation lies above the basal Beaverhill Lake anhydritic shale and below the upper Beaverhill Lake calcareous shale.

Twenty rock types representing depositional environments within the reef are recognized in the Dark and Light Brown units.

Stromatoporoids are responsible to a large extent for the organic framework of the hydrocarbon-producing bioherm; they are common in the biostrome and become profuse in the overlying bioherm. Algae, crinoids, corals, brachiopods, ostracods and molluscs provide additional information for environmental interpretations.

Reef development is divided into four stages which are represented by the depositional sequence of (1) an unfossiliferous basal anhydritic shale, (2) the biostrome, (3) the bioherm consisting of organic reef framework to the east and quiet-water sediments to the west, (4) the overlying shales representing subsequent inundation of the bioherm. Neither the biostrome nor the bioherm were above water during Beaverhill Lake time.



The Ante Creek Reef is unique among reefs of Swan Hills age for several reasons: it is located, with northwest Ante Creek, to the west of all other reefs of Swan Hills age; it has an area of major organic growth on the east side only; it possesses no green shale markers, calcarenite reef cap, definite Fort Vermilion Formation or basal coral beds; and it has a thicker sequence of upper Beaverhill Lake shale.



### ACKNOWLEDGEMENTS

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## INTRODUCTION

### GENERAL

The discovery well in the Ante Creek Field, Atlantic Ante Creek 4-7-65-23 W5M was completed November 29, 1962, with an initial potential of 114 B.O.P.D. In 1965 the total annual production was 400,503 barrels of 43.5° A.P.I. gravity oil and by June, 1966, thirty-two gas, oil and dry wells had been completed. The most recent well, Pan Am F-1 Ante Creek was completed August 25, 1968 with a flow of 300 B.O.P.D. The primary oil producing zone is a porous dolomite interval within the Light Brown unit (bioherm stage) of the Swan Hills Formation of the Beaverhill Lake Group. Commercial quantities of gas are present in the Dunvegan and Viking Formations.

### OBJECTIVES

The principal objectives in the Ante Creek Reef study are to describe the organic and lithologic content as well as the paleogeomorphology and paleogeography of the reef, and to trace the development of the reef complex from the initial biostrome stage through the subsequent bioherm stage. In order to establish the facies geometry of the reef it is necessary to:

- 1) Examine the character and distribution of reef sediments.
- 2) Identify the major organic constituents and trace their distribution.
- 3) Divide the reef deposits into paleoenvironmental facies.



### METHOD OF INVESTIGATION

Ten wells (Table 1) were selected in the Ante Creek Field on the basis of completeness of core, total length of core and paleogeomorphologic location on the reef complex. These cores were slabbed and the flat surfaces examined under a binocular microscope. Samples collected for every facies change were etched in 10% hydrochloric acid, coated with a glycerine and water mixture and studied by binocular microscope. One-hundred and thirty thin sections and one-hundred acetate peels were made of environmentally significant rock samples and observed under a petrographic microscope. In order to make visual estimations of percent dolomite, the stain alizarin red S was used. Both stained thin sections and peels provided detailed petrological information. Photographs of thin sections (X2.5) and photomicrographs (X10 and X25) were taken for compilation of the plates. Also, polished surfaces of rock samples were photographed to record large organic and sedimentary features. Contacts between lithologic units not intersected by the cores were picked from the electric, gamma ray and sonic logs. The datum line used for the construction of cross-sections A-A' (Figure 9) and B-B' (Figure 10) is the contact between the Beaverhill Lake Group and the basal shale unit of the Woodbend Group. Several attempts were made to extract microfossils from promising-looking rock samples but the efforts proved fruitless. A check list (Table 2) was devised to include most of the major petrological and organic criteria used for environmental interpretations.



TABLE OF WELLS STUDIED

NAME	LOCATION	K.B. ELEV.	TOP OF SWAN HILLS		INTERVAL LOGGED
			ELEVATION	SUBSEA	
PAN AM C-1 Ante Creek	Lsd 4-4-65-24W5M	2540'	11504'	- 8964'	- 8794'
PAN AM B-5 Ante Creek.	Lsd 10-27-65-24W5M	3009'	11,408'	- 8399'	- 8232'
HOMESTEAD B-38 Ante Creek	Lsd 10-23-65-24W5M	2836'	11,204'	- 8368'	- 8201'
PAN AM B-1 Ante Creek.	Lsd 10-13-65-24W5M	2846'	11,188'	- 8342'	- 8175'
ATLANTIC Ante Creek.	Lsd 10-18-65-23W5M	2778'	11,235'	- 8457'	- 8350'
PAN AM D-1 Ante Creek	Lsd 4-8-65-23W5M	2796'	11,172'	- 8376'	- 8250'
ARCO Ante Creek.	Lsd 10-6-65-23W5M	2797'	11,170'	- 8373'	- 8166'
ATLANTIC Ante Creek	Lsd 4-15-65-24W5M	2900'	11,388'	- 8488'	- 8188'
PAN AM B-2 Ante Creek.	Lsd 4-25-65-24W5M	2891'	11,232'	- 8341'	- 8219'
PAN AM B-8 Ante Creek.	Lsd 10-25-65-24W5M	2810'	11,290'	- 8480'	- 8408'



DATE		WELL NAME					
K.B.		T.D.		LOCATION		FMN.	
INTERVAL		FT. CUT		FT. REC.			
		1	LITHOLOGY				
		2	GRAIN SIZE				
		3	COLOR				
		4	ROUNDNESS				
		5	SORTING				
		6	PACKING				
		7	TYPE	POROSITY			
		8	GRADE				
		9	INTRACLASTS		7.		
		10	CORALS		FRAMEWORK		
		11	STROMS.		> 2mm.		
		12	ALGAE				
		13	SKELETAL				
		14	PELLETS		%		
		15	INTRACLASTS		GRAINS		
		16	LITHOCLASTS		2-03mm.		
		17	COATED GRNS				
		18	AVE.GRN. SIZE				
		19	MICRITE	MATRIX			
		20	SP. CALCITE				
		21	DOLOMITE	CEMENT			
		22	ANHYDRITE				
		23	DOLOMITE		DETrital		
		24	FELDSPAR		+ ACCESSORY		
		25	CLAY		MINERALS		
		26	PYRITE				
		27	CARBON				
		28	CHLORITE				
		29	OTHERS				
		30	PORE FILLING NON-CEMENT				
		31	MASSIVE		% STROMS		
		32	TABULAR				
		33	BRANCHING				
		34	BULBOUS				
		35	AMPHIPORA				
		36	% CORALS				
		37	WHOLE		% BRACHS		
		38	BROKEN				
		39	% CRINOIDS				
		40	SOLENOPORA		% ALGAE		
		41	COATED				
		42	MAT				
		43	% GASTROPODS				
		44	% PELECYPODS				
		45	% FORAMS				
		46	% OSTRACODS				
		47	STRATIFICATION	PRIMARY			
		48	OTHERS				
		49	FRACTURES				
		50	STYLOLITES	SECONDARY			
		51	OTHERS				
		52	TYPE	DIAGENESIS			
		53	DEGREE				
		54	FURTHER DESCRIPTION				
		55	FOOTAGE				
CHECK LIST FOR FACIES DESCRIPTIONS							

TABLE 2



### REGIONAL AND STRUCTURAL SETTING

The Ante Creek Reef Complex is located in the subsurface of west central Alberta in Townships 64 to 66, Ranges 23 and 24, west of the fifth meridian. It lies approximately 175 air miles northwest of Edmonton in an area immediately southwest of Sturgeon Lake (Figure 1).

The reef is situated on the east limb of the Alberta syncline, downdip from the Kaybob-Goose River-Snipe Lake reef chain. A regional dip of 62 feet per mile to the southwest is evident from subsea elevations on the base of the Beaverhill Lake Group. In plan view, the Ante Creek Reef Complex is separated from the Peace River arch to the north by the Sturgeon Lake Reef and is bounded on the south side by the Simonette-Berland River Complex (Figure 1). The Western Alberta ridge strikes in a north-northwest direction to the west of Ante Creek. Six miles to the northwest lies Northwest Ante Creek, a much smaller reef of Swan Hills age. Ante Creek is the most westerly located reef complex of the Beaverhill Lake Group.

### SUMMARY OF PREVIOUS WORK

In 1950, the Geological Staff of Imperial Oil Ltd. proposed the name Beaverhill Lake Formation for a sequence of limestones and shales lying above the Elk Point Group and below the Cooking Lake Formation in the Edmonton area. However, Warren (1933) had termed the equivalent of this interval in northwestern Alberta, the Waterways Formation. Crickmay (1957) subdivided the Waterways Formation into



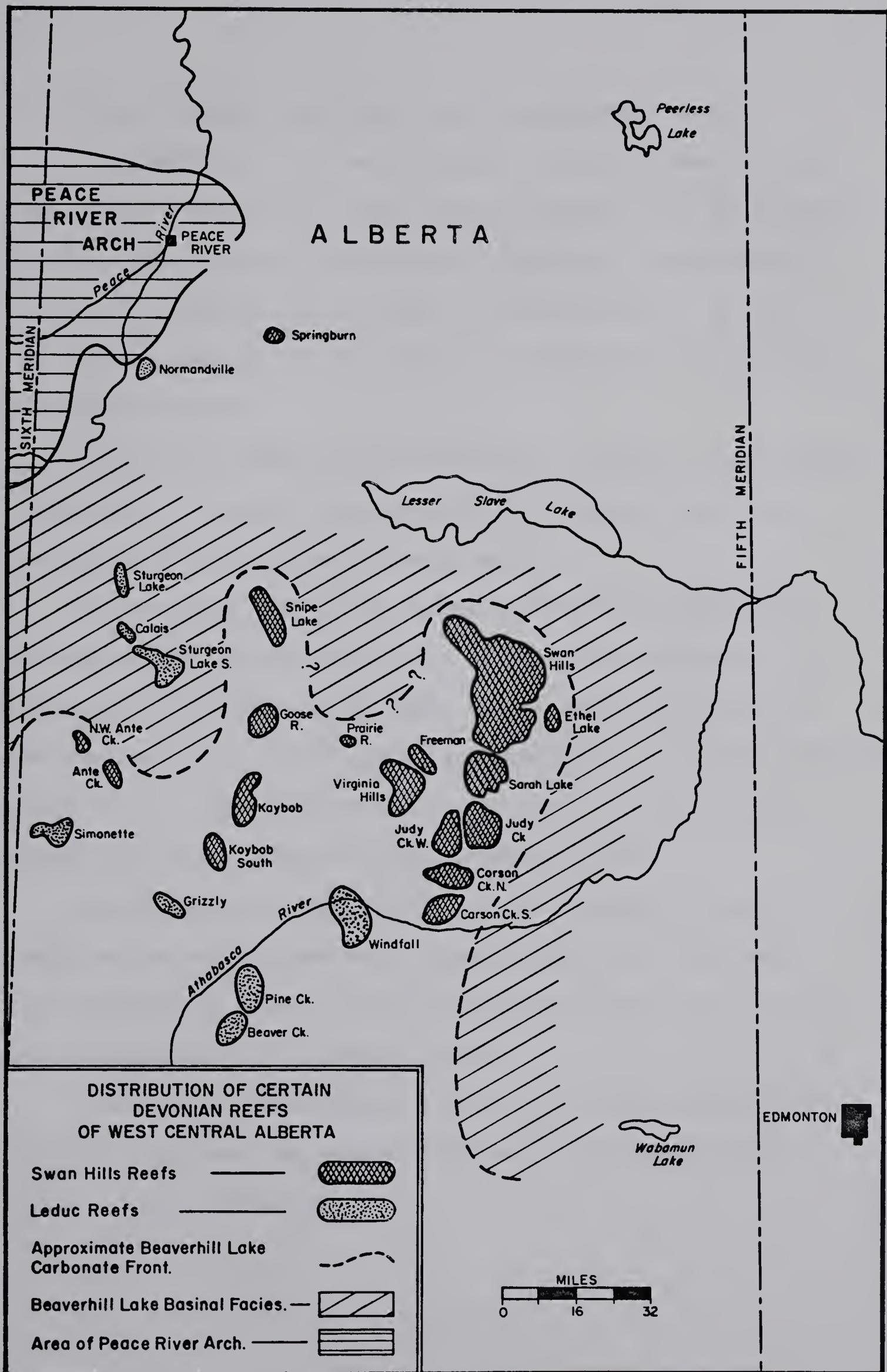


Figure 1



the Firebag, Calumet, Christina, Moberly and Mildred Members.

The Swan Hills Field was discovered in 1957 by Home Oil, and Fong (1960) introduced the term 'Swan Hills Member' for the sequence of reefal limestones at the base of the Beaverhill Lake Formation. Although he described the lithology and paleontology of the reef from several cores he did not produce an ecological interpretation of the reef facies.

Edie (1961) mapped the Swan Hills Reef in terms of depositional environments using fossil types as well as sediment textures and provided an interpretation of reef growth.

Murray (1966) contributed further knowledge by presenting a thorough account of the environments of deposition during the development of the Judy Creek Reef. He discussed Judy Creek from the stratigraphical, petrological, paleontological and paleoecological points of view and suggested that the Swan Hills Member could be divided into nine lithological and biological units.

Jenik's thesis on the Goose River Field (1965) and Leavitt's thesis on the Carson Creek North Complex (1966) both contributed more lithological, paleontological and paleoecological data on the Swan Hills reefs of west central Alberta.

Fischbuch (1968) conducted a study of six reef complexes of Swan Hills age based on detailed observations of stromatoporoid morphology and paleoecology.



### QUALIFICATION OF TERMINOLOGY

In a reef study, it is necessary to understand the meanings of the terms reef, organic reef, bank, bioherm, and biostrome. Nelson, Brown and Brineman (1962) provided a thorough account of the evolution of reef terminology. The definitions employed in this thesis are after Klement (1967).

The terms "reef" and "bank" denote the origin of the structures. A reef is a prominent wave-resistant feature constructed by in situ framebuilding organisms and is capable of influencing the local sediments. In situ organic growth predominates over sediment trapping and binding and the organisms have the ability to elevate the reef above the surrounding sea floor. In contrast, a bank is composed of organisms that were unable to construct a rigid frame-work. It is wave-resistant and may be composed of transported skeletal material or in situ organisms, the latter which may be responsible for the binding or baffling of sediments. A bank may or may not be a prominent feature, elevated above the surrounding sediments.

The "organic reef" is that portion of the reef constructed by in situ organisms responsible for the wave-resistant nature of the structure.

"Bioherms" and "biostromes" are differentiated on the basis of shape. A bioherm is a massive, mound-shaped structure of variable horizontal extent and height with steep flanks and a lithology quite different from the surrounding layered facies. On the other hand a



"biostrome" is roughly bedded and grades concordantly into the adjacent sediments of equivalent age but different lithology.

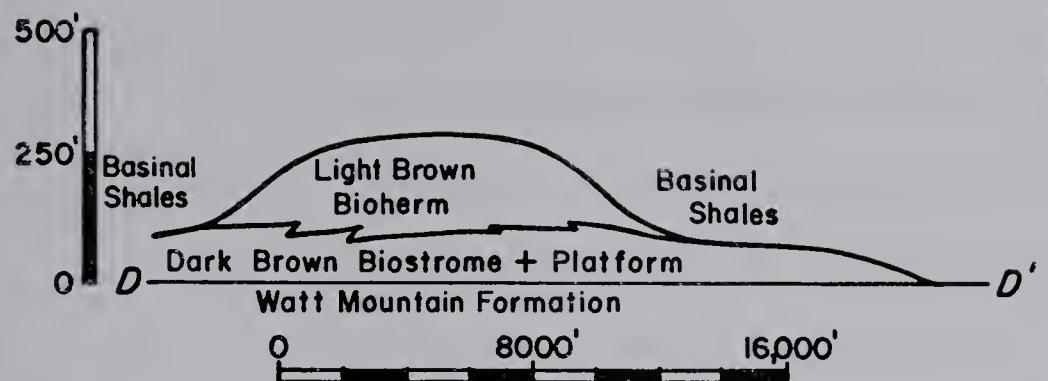
#### PALEOGEOGRAPHY AND PALEOTOPOGRAPHY OF THE ANTE CREEK REEF

The Ante Creek Reef Complex (Swan Hills Formation) is Middle to Late Devonian in age, belonging to the late Givetian-early Frasnian Stages (Leavitt and Fischbuch, 1968). Other reefs of similar age include Snipe Lake, Virginia Hills, Kaybob, Carson Creek, Judy Creek and Swan Hills. These reefs developed on finger-like projections of the Beaverhill Lake carbonate reef platform which extended into the deep water of the Beaverhill Lake sea to the north (Figure 2). Ante Creek and Northwest Ante Creek lie to the west of the earlier-discovered reefs of Swan Hills age. Ante Creek is separated from the Kaybob-Goose River-Snipe Lake reef chain by basinal shale sediments which indicate a deep embayment.

During Beaverhill Lake time, the Peace River arch was a positive feature rising as isolated knobs above water level (Bassett and Stout, 1967). Middle and Upper Devonian sediments thin in the vicinity of the Peace River arch. The basinal shales thicken from Carson Creek northward to Judy Creek and Swan Hills, and westward from Carson Creek to Ante Creek. These shales, which constitute the upper Beaverhill Lake sediments of this thesis thicken as the Swan Hills Formation thins. The thick sequence of basinal shales in the Ante Creek area suggests that this reef grew on the edge of a deep basin. Bassett and Stout



GENERALIZED DIAGRAM  
OF THE ANTE CREEK REEF  
Contour Interval = 50'



LEGEND

- Oil Well.
- ★ Gas Well.
- ◇ Abandoned Well.

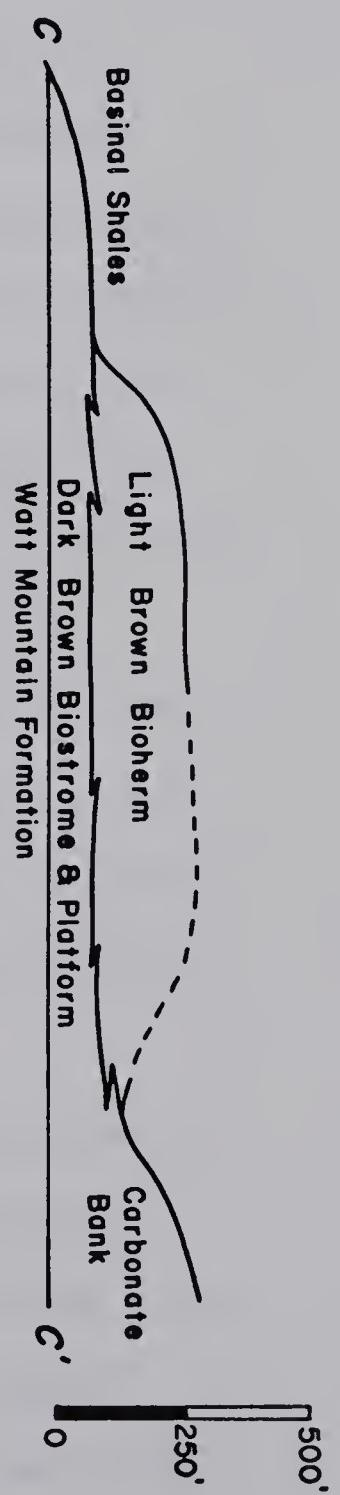
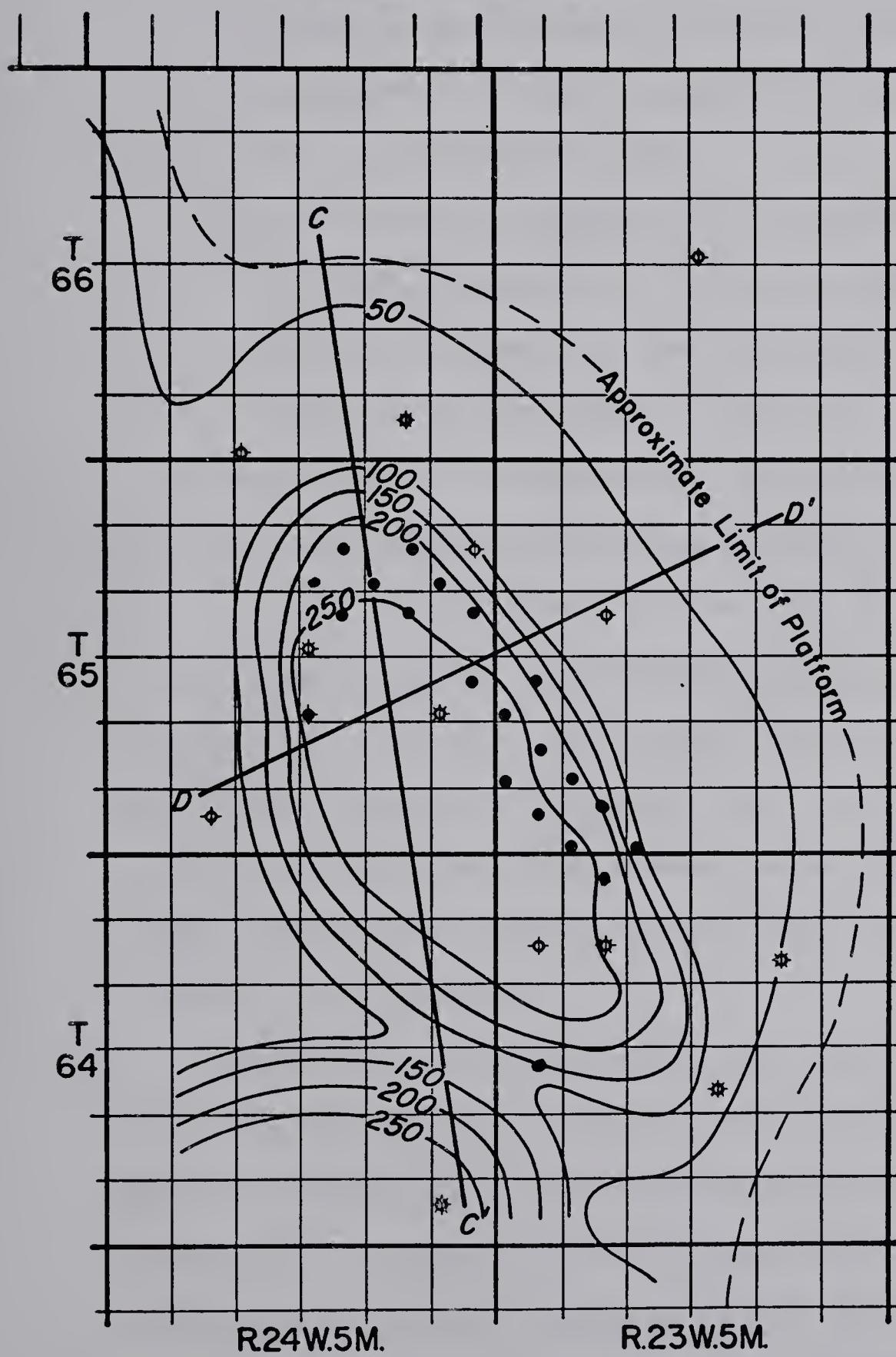


Figure 2



(1967) suggested that the Western Alberta ridge was under water during the Upper Devonian. It is probable that a deep area of the basin extended between Ante Creek and the Peace River arch and continued westward. This deep channel would account for the active reef growth on the north and northeast sides of Northwest Ante Creek and Ante Creek as the currents and winds swept southward and westward around the eastern end of the Peace River arch.

The Ante Creek Reef appears to be a reef-fringed carbonate bank of low relief, composed of a broad biostromal stage grading into carbonate bank sediments to the south, and an overlying biohermal stage of smaller lateral dimensions (Figure 2). The bioherm represents the true reef whereas the biostrome is by definition (Page 8) a bank structure. Ante Creek is an elongate structure of approximately 25 square miles trending northwest-southeast and is a maximum of 250 feet thick (Figures 2 and 4). The reef-front has an average dip of 1.5 degrees to the northeast. This gradual slope explains the lack of a well-developed fore-reef talus zone. Ante Creek is separated from Northwest Ante Creek by a deep channel in the vicinity of well 4-4-65-24 W5M. The northwest edge of the Ante Creek Reef dips approximately 5 degrees to the northwest.

Figure 3 is a structure contour map of the Swan Hills Formation. It is necessary to remove the regional dip of 62 feet per mile in a southwest direction by restoring the base of the Beaverhill Lake Group to horizontal in order to obtain the true reef topography before tilting. There is a prominent high area on the northwest end of the reef as indicated by well 4-22-65-24 W5M. Several prominent



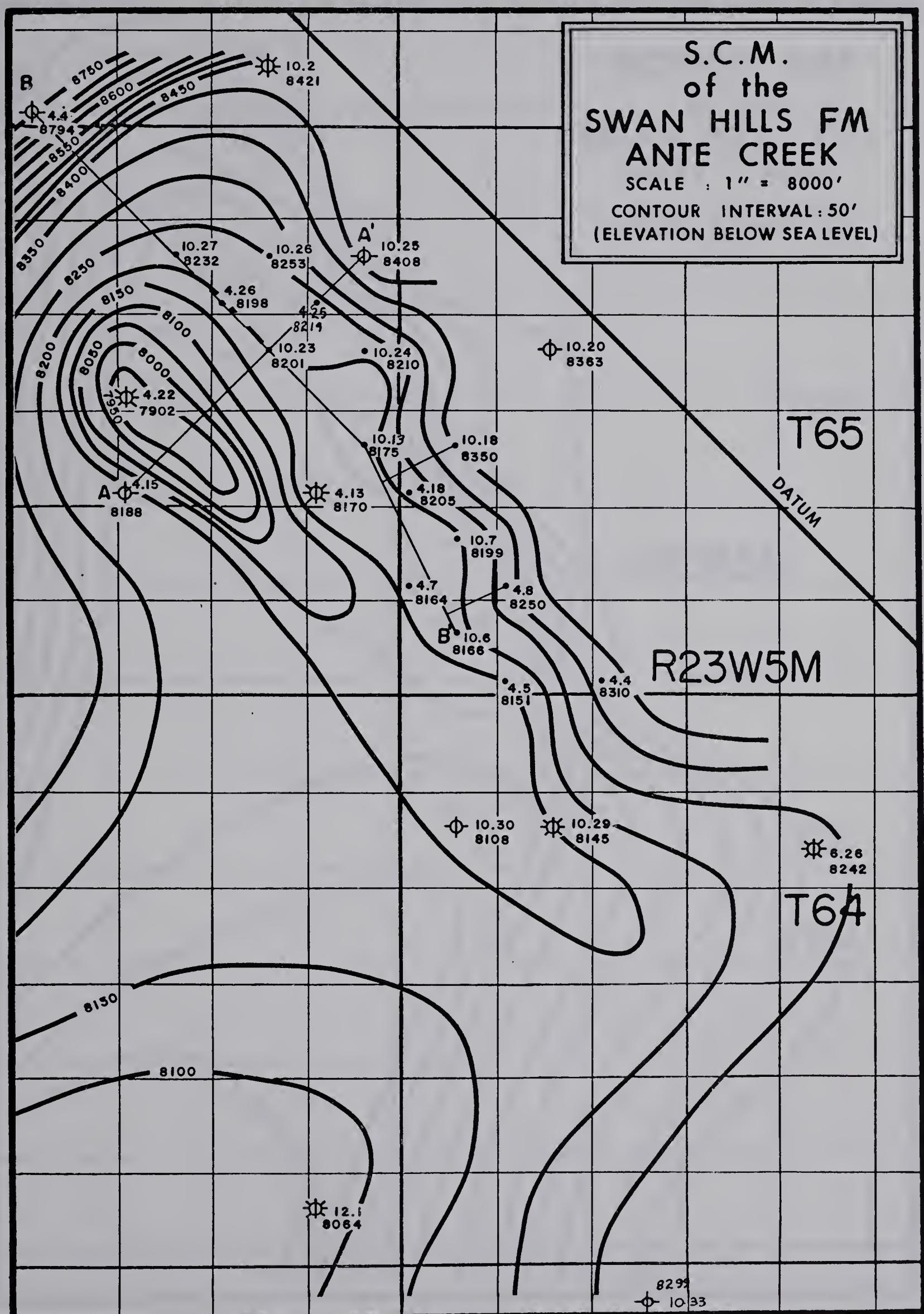
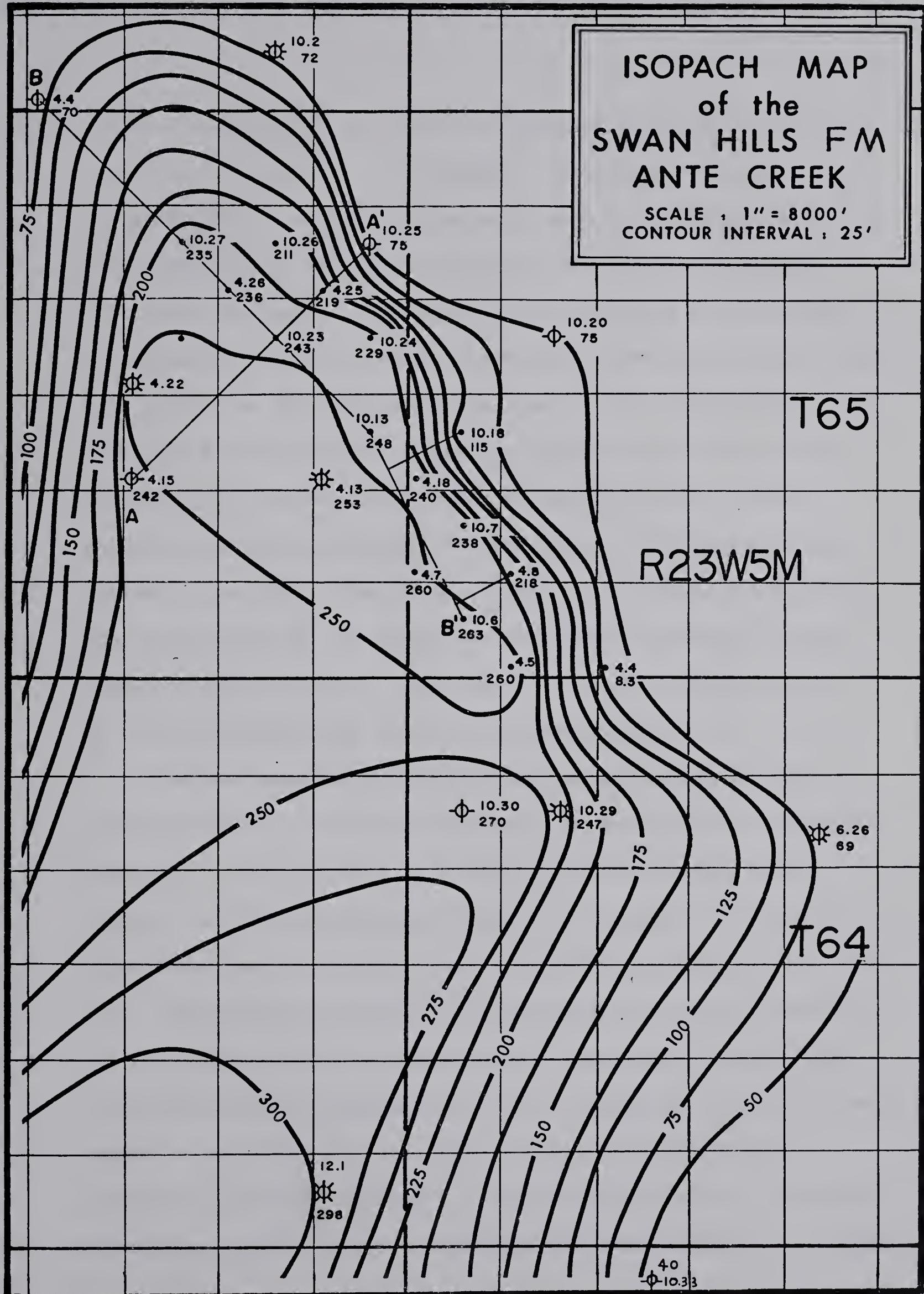


FIGURE 3

S.C.M. = STRUCTURE CONTOUR MAP

REGIONAL DIP REMOVED



**FIGURE 4**



reentrant channels on the reef-front indicate that the current and wind direction was from the northeast. These channels account for the difficulty in correlating facies between wells along line B-B'. During the channel development there was a vertical and lateral alternation of lagoonal facies and actively growing organic facies perhaps as the result of barrier formation across the channels. Poor well control on the south end of the reef renders the interpretation of Figure 3 speculative. The general configuration of Ante Creek is that of an elongate reef grading southward into the platform sediments with deep basins to the east and west and having a deep channel to the north (Figure 2). Figure 4 is the isopach map of the Swan Hills Formation and shows the thickening of sediments in the immediate Ante Creek area. The edge of the reef platform (Figure 2) is to the north and east of the area shown in Figure 3.

The reef appears to have developed on a protrusion of the Beaverhill Lake reef platform into the deep waters of the Beaverhill Lake sea. It is difficult to define the vertical limits of the platform on which the reef grew because of the gradational contact between the basal Beaverhill Lake shales and the overlying Dark Brown unit. The elevated portions of the platform on which the reef was initiated are probably the expression of underlying basement highs which formed by faulting (Martin, 1967). Compaction of the soft basinal sediments was likely a minor factor in the shallowing of the platform in the Ante Creek area. Electric and mechanical log studies indicate no draping of upper Beaverhill Lake carbonates over the reef.



## STRATIGRAPHY

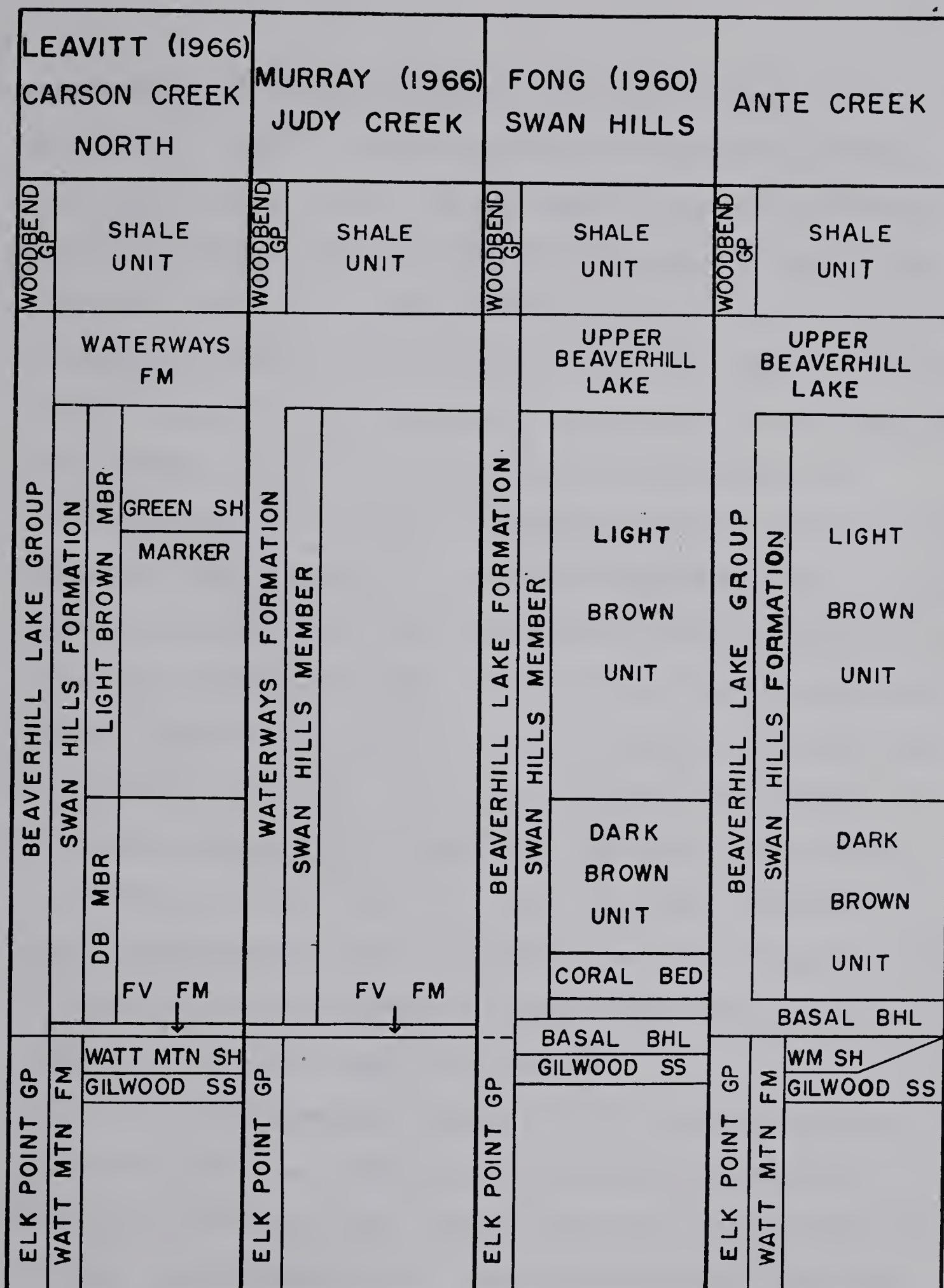
### NOMENCLATURE

Selected interpretations of the stratigraphic nomenclature are illustrated in Figure 5.

The writer acknowledges the recent alterations in the Devonian nomenclature of the Swan Hills area by Leavitt and Fischbuch (1968). These changes are not included in Figure 5 because they involve only group and formation status, not stratigraphic correlations. Leavitt and Fischbuch (1967) have officially raised the Beaverhill Lake Formation to group status, including in it the Fort Vermilion, Swan Hills and Waterways Formations after Leavitt (1966).

The writer prefers to use the term basal Beaverhill Lake after Fong (1960) for the laminated black to dark brown anhydritic shale that lies above the Watt Mountain Shale and Gilwood Sandstone. The basal Beaverhill Lake is a gradational unit and is difficult to define. It does not contain the dark brown dense anhydrite beds of the Fort Vermilion Formation as described by Leavitt and Fischbuch (1968). Also, the unit is only an average of ten feet thick in the Ante Creek area (Figures 9 and 10) in contrast to a thickness of 40 feet given to the Fort Vermilion Formation in the area immediately north of Swan Hills. "Upper Beaverhill Lake" is the name given in this thesis for the sequence of limestones and calcareous shales lying above the Light Brown unit and below the Woodbend Group shale. From the resistivity curves, the sequence of units can be picked as follows:





LATE MIDDLE DEVONIAN AND EARLY UPPER DEVONIAN STRATIGRAPHIC NOMENCLATURE

FV=FORT VERMILION  
WM=WATT MOUNTAIN

FIGURE 5



a calcareous shale interval directly above the Light Brown unit, an overlying limestone interval followed by an overlying calcareous shale then a limestone unit. This sequence of interbedded limestones and shales has been termed the Virginia Hills Member by Jenik (1965). "Waterways" was the term applied by Leavitt and Fischbuch (1968) to include the sediments directly above the reefs of Swan Hills age as well as the off-reef deposits. It is the writer's opinion that the terms basal and upper Beaverhill Lake should be applied in this thesis for the following reasons: the section is localized; the basal Beaverhill Lake shales are gradational with the Dark Brown unit and represent a sequence grading from the Elk Point restricted sediments into the Beaverhill Lake carbonates; the Light Brown unit grades into the upper Beaverhill Lake shales. Figure 5 illustrates the Swan Hills Formation as lying within the Beaverhill Lake Group. The writer employs the term Waterways for the basinal equivalent of the Beaverhill Lake Group. This serves to differentiate the basal Beaverhill Lake - Swan Hills Formation - upper Beaverhill Lake sequence from the basinal shale equivalent. Neither the upper nor the basal Beaverhill Lake sediments are recognized as formal units, hence the lower case spelling.

The Swan Hills Formation consists of a lower Dark Brown unit, approximately 100 feet thick and an overlying Light Brown unit approximately 150 feet thick. The Dark Brown unit grades upward into the Light Brown biohermal unit. These two units define two stages of reef development, i.e. the lower biostrome and the overlying bioherm. Fong (1960) included a coral bed at the base of the Dark Brown unit but no corresponding lithology is present at Ante Creek.



Furthermore, the green shale marker in the upper part of the Swan Hills Formation at Carson Creek North (Leavitt, 1966) is not recognized here. The subdivisions of the Waterways Formation, namely the Firebag, Calumet, Christina, Moberly and Mildred Members as applied by Crickmay (1957) in northwestern Alberta do not apply in this area because there are no recognizable shale units in the Swan Hills Formation.

A trace of Watt Mountain Shale is present in Pan. Am. C-1 Ante Creek 4-4-65-24 W5M and is included in Figure 5 between the Gilwood Sandstone below and the basal Beaverhill Lake above. Fong (1960) described the basal Beaverhill Lake as a greenish-black calcareous shale. Because the Watt Mountain Shale closely fits this description, it would appear as though he was including the Watt Mountain Shale as well as the lower beds of the Swan Hills Formation in the basal Beaverhill Lake. A definite Watt Mountain green shale 10 feet thick is found in only one well, namely Pan. Am. C-1 Ante Creek. It is easily distinguished from the overlying basal Beaverhill Lake anhydritic shale and from the underlying Gilwood quartz sandstone.

A non-calcareous shale unit of the Woodbend Group overlies the Beaverhill Lake Group and consists of black and greenish-grey fissile shale. This shale tends to have a low resistivity, a low sonic reading and a moderate gamma-ray count. Thus, they are easily discernible on the electric and mechanical logs. The contact between the Woodbend and Beaverhill Lake Groups is chosen where a rapid increase in resistivity occurs with increase in depth. This break is sharp, indicating a well-defined change in lithology from shale above, to limestone below.



## CORRELATIONS

The sequence of interbedded limestones and shales termed the Beaverhill Lake Formation in the Edmonton area by the Geological staff, Imperial Oil Limited (1950) was found, after active drilling in the Waterways-Fort McMurray region of northeastern Alberta, to be approximately equivalent to the Waterways Formation. The latter had been named by Warren (1933) and was subsequently subdivided by Crickmay (1957) into the Firebag, Calumet, Christina, Moberly and Mildred Members in ascending order. Similar alternating limestone and shale units are recognized in the Beaverhill Lake Formation of central Alberta, although the limestone intervals are much thicker there. North of Fort McMurray, the shale units become progressively thicker and are equivalent to the basal part of the Hay River Formation of the Great Slave Lake region. The Beaverhill Lake Group thins westward over the Peace River arch and is correlative with the basal units of the Fort Simpson Formation of northeastern British Columbia and northwestern Alberta. In these areas, the underlying Slave Point may be equivalent to the Dark Brown unit of the Swan Hills Formation. The Slave Point Formation appears to grade southward from the Great Slave Lake area into the basal Swan Hills beds in the Edmonton region. The upper beds of the Beaverhill Lake Group are correlative with the upper part of the Flume Formation which lies south of the Athabasca River in the Front Ranges of the Rocky Mountains. Lower units of the Beaverhill Lake Group are found in the Flume Formation north of the Athabasca River (McLaren, 1962). Interbedded anhydrites, dolomites



and limestones of the Souris River Formation of Saskatchewan, Montana and North Dakota represent the evaporitic phase of the Beaverhill Lake Group that passes from the central Alberta basin to the Saskatchewan shelf.

### PETROLOGY

#### CLASSIFICATION

In any reef study the classification used to name the rock types will be unique for the particular region under consideration. It is essential to have a terminology which is expressive of the type, relative abundance and size of the constituents, and elastic enough to describe most of the sediments encountered. The classification chosen in this thesis was that of Leighton and Pendexter (1962) which the writer modified to suit the particular case of the Ante Creek Reef. In order to produce a classification scheme which would encompass most limestone types found in the Ante Creek Reef, the writer integrated the limestones produced by in situ organisms with those of clastic organic or inorganic origin. In the classification chart of Leighton and Pendexter (1962) the in situ organic framework is separated and classed as "organic framebuilders". To the basic names applied by Leighton and Pendexter (1962) were added the grain-size terms of Grabau (1913, 1914). This clarifies the size range into which the organic or inorganic constituents composing greater than 50 percent of the rock are placed. The classification proposed for the Ante Creek



lithology is based on composition (type of grains), depositional texture (size and sorting) and depositional environment. The grain size classification of Grabau closely parallels the Wentworth Scale for sedimentary particles:

calcirudite ----- >2 mm.

calcarenite ----- 0.06 - 2 mm.

calcilutite ----- <0.06 mm.

All particles less than 0.06 mm. in size are considered to be in the calcilutite range (micrite). This size division is arbitrary and is based on thin section observations. It was decided that no environmental significance would be gained by subdividing the size ranges into fine, medium and coarse. Grabau (1913, 1914) referred to calcirudite as "limestone or dolomite composed of broken or worn fragments of coral shells, or of limestone fragments, the interstices filled with calcite, sand or mud and with a calcareous cement." This definition has a genetic meaning, suggesting a rubble of skeletal or limestone particles having been swept together, then cemented. However, the writer employs the term strictly in the textural sense (particle size) and uses it to identify fragments of rubble transported to a site of deposition as well as in situ fossil material greater than 2 mm. in size.

The altered classification of Leighton and Pendexter as illustrated in Table 3, does not include sparite or dolomite; however, these terms may be used as modifiers e.g. dolomitic skeletal calcirudite. When the opportunity arose to employ a term such as "pellsparite" (Folk, 1962) the writer did so. The size of pellets is defined in this thesis



		CLASSIFICATION OF LIMESTONE TYPES			
Allochems Micrite	% Allochems	In Situ and Transported Skeletal Material	Pellets	Oolites	Intraclasts
	> 50% > 2 mm.	> 50% 0.06 - 2 mm.	0.06 - 2 mm.	0.06 - 2 mm.	> 50% > 2 mm. .06-2mm > 50% .06-2mm
		Skeletal Calcirudite	Skeletal Calcareous Pellet	Oolitic Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet
9:1		Skeletal Calcirudite	Skeletal Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet
	~90%	Skeletal Calcirudite	Skeletal Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet
	1:1	Skeletal Calcirudite	Skeletal Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet
	~50%	50% - 90% < 0.06 mm.	Skeletal Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet
	1:9	~10%	Skeletal Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet	Intraclastic Calcareous Oolitic Micritic Calcareous Pellet
					Micrite -----

Table 3



as being 2 mm. to 0.06 mm. in diameter. The term "intraclast" (after Folk, 1962) designates "fragments of penecontemporaneous, generally weakly consolidated sediment that have been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment." In size, intraclasts can range from very fine sand to boulders.

This classification provides a concise description of each rock type encountered in the Ante Creek Reef.

#### GENERAL NATURE OF THE SEDIMENTS

The Ante Creek Reef Complex is composed of limestone, for the most part produced either directly or indirectly by organic activity. Quartz sandstone was recognized in the Beaverhill Lake Group only across the gradational contact between the Gilwood Sandstone and the overlying basal Beaverhill Lake. Although there are locally concentrated bands of argillaceous-rich limestone, especially within the Dark Brown unit, the dark brown color appears to be chiefly a result of bituminous material. Only a moderate amount of secondary dolomite is apparent in the Ante Creek Reef with concentrations within the light brown bioherm stage.

The oldest formation penetrated in the wells examined for this thesis is that of the Gilwood Sandstone of the Watt Mountain Formation. It occurs in four wells (Figures 9 and 10) and consists of medium to coarse grained sand-sized quartz and feldspar detritus with fine pebble bands cemented by anhydrite, dolomite and rarely calcite (Plate 6, Figure 7). This deposit is thought to have been derived from



the Peace River arch and the Western Alberta ridge during late Elk Point time. It represents an extensive clastic influx into the Elk Point basin. Thin section studies indicate replacement of the dolomite and calcite cement by anhydrite. This replacement may have taken place while restricted conditions prevailed during the deposition of the basal Beaverhill Lake shale. A detailed discussion of the Gilwood Sandstone is not within the scope of this thesis.

Watt Mountain green chloritic shales were encountered in only one well, 4-4-65-24 W5M (Figure 10). This ten-foot interval consists of medium to light green shale interbedded with white to pink calcite and exhibits a boudinage-like structure (Plate 6, Figure 8).

Above the Watt Mountain Formation lies a laterally persistent ten-foot sequence of finely laminated dark brown to black anhydritic shale termed basal Beaverhill Lake. It has a moderate to high argillaceous-bituminous content and contains scattered, poorly sorted quartz grains within the lighter-colored laminae (Plate 7, Figure 1). The calcareous content increases from negligible at the base of the unit to moderate at the top. There is no recognizable skeletal material within the basal Beaverhill Lake shales.

The basal Beaverhill Lake sediments grade vertically into the overlying Dark Brown unit with an increase in calcite content and the disappearance of anhydrite. The lowermost lithology of the Dark Brown unit consists of a skeletal limestone referred to as facies "A" (Figures 9 and 10). This interval is characterized by sedimentary 'boudinage' structures which superficially resemble chains of sausage in shape.



These chains are commonly detached and fragments 1 to 5 cm. in diameter lie as single intraclastic bodies in a micrite matrix. Crinoid and brachiopod fragments are concentrated within the matrix which encloses the boudins, although there is a low percentage of this skeletal material in the boudins (Plate 7, Figure 2). Both the boudins and the enveloping matrix are composed of dark brown, bituminous-argillaceous micrite. These structures formed by pre-lithification compaction of the soft lime muds during the early stages of biostromal development. The remainder of the Dark Brown unit consists of organic framebuilders and skeletal fragments embedded in a calcarenite and micrite sedimentary matrix. Micrite constitutes a minor contribution to the Dark Brown unit as a whole. Pellets (Plate 7, Figures 4 and 5), oolites (Plate 7, Figure 4), intraclasts (Plate 7, Figures 5 and 6) and skeletal fragments (Plate 6, Figures 1 to 4) contribute to the matrix in which the in situ framebuilders lie. There are minor occurrences of well-sorted pellet beds (Plate 7, Figure 5) a few inches thick in which well-rounded pellets are cemented by sparry calcite. Intervals which superficially appear to be composed of micrite, on close inspection contain vague outlines of pelletal or intraclastic shape (Plate 7, Figure 6). These "ghosts" may have been the result of compaction of the pellets by weight of the overlying lime mud when the allochems were still soft. However, this feature may have been formed by solution and recrystallization after lithification of the sediments. A large proportion of the micrite contains laminae which can be interpreted as resulting from quiet-water in organic deposition, or algal precipitation (Plate 5, Figure 3).



Particular intervals of this (algal) micrite contain moderate amounts of sparry calcite included within the laminae resulting in the familiar birdseye structure.

Overlying the dark brown biostrome and gradational with it is the light brown bioherm. The light brown color results from the increase of sparry calcite and the decrease of bituminous-argillaceous matter. This interval represents the stage of profuse organic growth as indicated by the high concentration of in situ organic framebuilders. There are units composed almost entirely of stromatoporoids. The allochem content of the matrix enclosing the organic material is similar in composition to that of the Dark Brown unit although the occurrence of sparry calcite is more frequent.

#### DIAGENESIS

The principle types of post depositional alteration considered in this thesis are: secondary dolomitization, recrystallization of micrite, stylolite formation and pyritization.

Two forms of secondary dolomitization are differentiated in this study i.e. sucrosic dolomitization of the matrix and vug lining by euhedral dolomite crystals. The writer uses the term 'sucrosic' to refer to single scattered dolomite rhombohedra as well as masses of dolomite rhombs, completely or in part replacing the limestone matrix. Well-defined dolomite rhombohedra 0.05 - 0.8 mm. in size are distributed at random throughout the sedimentary matrix (Plate 7, Figure 7). There are thin intervals within the producing zone (lower part of the Light Brown unit) in which the limestone matrix is



completely replaced by dolomite rhombohedra. Although the primary pore space of the organic framework contains secondary dolomite, the organic framework is still calcitic in composition (Plate 4, Figure 2). Perhaps the dense nature of the skeletal material prevented penetration by magnesium-rich waters and thus blocked magnesium-calcium ion exchange. In this porous dolomitized matrix, traces of light brown solid hydrocarbons are frequent. In the Light Brown unit there are intervals containing vugs from 2-20 mm. in diameter. These vugs may be totally or partially filled by white dolomite crystals from 0.2 - 15 mm. in diameter, commonly with curving crystal faces. Finely crystalline calcite and solid bitumen, the latter in the form of fine black flakes 0.05 - 0.3 mm. in diameter, frequently accompany the dolomite crystals lining the vugs. It is possible that a small amount of anhydrite exists in those crystal growths although none was recognized. The dolomite crystals within the vugs were formed by ion exchange between the vug walls and magnesium-rich connate waters. The latter were responsible for increasing the size of the vugs by solution. Several examples of dolomite rhombohedra "floating" in sparry calcite crystals suggest dedolomitization, although evidence for this process is insufficient. This type of crystal structure showed up well when the sample was etched in dilute hydrochloric acid, then stained with alizarin red S. The association of both euhedral dolomite and euhedral calcite crystals in vug linings may be a result of dedolomitization or contemporaneous crystallization resulting from slight changes in the geochemical environment within the vug. The distribution of dolomite



is illustrated in the ~~Plates~~ included in Appendix I.

Secondary sparry calcite is found throughout the Light Brown and Dark Brown units in the form of scattered sand-sized crystals or as blebs representing areas where the micrite muds and/or micrite allochems have been replaced (Plate 7, Figure 6). Where the contacts between sparry calcite concentrations and the surrounding micrite or allochem matrix appear to penetrate the sparry calcite, secondary replacement is assumed. The writer considers birdseye calcite (Plate 5, Figure 3) to be algal in origin where the spaces once occupied by algal structures became filled by sparry calcite. Thus, sparry calcite appears to be a void-filling precipitate as well as the secondary replacement product of micrite.

Stylolites of large and small amplitudes are found throughout the reef sediments (Plate 7, Figure 8), the highest concentration being within the Light Brown unit, commonly between stromatoporoid fragments. The stylolitic surfaces are composed of solid bitumen and/or argillaceous material that was deposited along the plane of the stylolite during solution. There are a few in which pyrite has been deposited, but these are not frequent. As with most of the diagenetic effects, stylolites are most common in the producing zone of Ante Creek at the base of the Light Brown unit.

Pyrite is present in the carbonate sediments in very small amounts, usually less than one percent in the pyrite-bearing facies. It occurs in three forms: finely disseminated flakes, blebs less than 0.5 mm. in diameter or as a replacement mineral in organic skeletons



or oolites. It is possible that a large quantity of the pyrite flakes may be primary, as this form is commonly located in those carbonate facies deposited in a quiet-water environment. If this is so, then the presence of euxinic conditions in the small restricted lagoonal areas on the reef-flat could easily have contributed to the formation of pyrite. However, the pyrite is largely secondary in nature and probably crystallized from connate waters percolating through the carbonate muds after deposition. This form of pyrite is found throughout the reef, from the dark brown platform through the light brown bioherm. One interesting example of secondary pyritization is in a sample of calcareous shale, containing a thin band of fine-grained oolites having clear calcite centres and pyrite coatings (Plate 7, Figure 9)

#### POROSITY

Related to diagenetic processes but deserving a separate heading, the porosity is an economically valuable characteristic of reef sediments. Visual estimates of the total porosity in the carbonate sediments were made with a range of accuracy of 5% which was sufficient to show the gross relation between porosity, dolomitization and facies type.

Examples of several types of porosity were found throughout the reef, particularly in the lower intervals within the Light Brown unit. The two major divisions are primary and secondary. These principal types can be further subdivided into intergranular, interskeletal, intraskeletal, intercrystalline and fracture porosity. The terms



pin-point and vuggy refer to the size of the cavities.

Primary porosity consists of vacuities remaining in the matrix (intergranular, intercrystalline), within the framework of certain organisms such as stromatoporoids, algae, etc. (intraskeletal) and between organic fragments and masses (interskeletal). Primary porosity appears to have allowed the initial influx of magnesium rich solutions which both enlarged the cavities and initiated dolomitization and recrystallization. In the case of secondary porosity, new pore spaces formed in the lithified deposit where previously the limestone matrix had been dense. Planes of weakness between skeletal material (interskeletal) and easily dissolved zones between grains or crystals in the primary framework allowed the development of secondary porosity followed by recrystallization and dolomitization. If the cavities are enlarged so that they exceed 1 mm. in diameter, they are regarded as vugs. Sizes less than 1 mm. are considered to be of the pin-point variety. Excellent examples of intraskeletal pin-point porosity are present in the massive stromatoporoid intervals of the Light Brown unit. Commonly this type of porosity is destroyed by deposition of sparry calcite and to a lesser extent by deposition of dolomite. This porosity would be expected in the open framework of the massive stromatoporoids. The frequency of discrete dolomite rhombohedra scattered throughout the matrix and known here as sucrosic dolomitization (Plate 4, Figure 2 and Plate 7, Figure 7) suggests initial intergranular porosity. The initial voids left between allochems due to current sorting are commonly filled by post-depositional sparry calcite. There are only minor occurrences of solid bitumen in the



pore spaces usually in the intervals of vuggy porosity.

The greatest accumulation of porosity is in the areas of the reef where the stromatoporoids are abundant, especially the massive types, and where the percentage of allochems is large. The most porous facies, therefore, are those which represent the reef-edge and the main reef core, comprising the zone of active reef growth and turbulence. Rock types representing sub-turbulent and lagoonal facies are relatively dense as a result of compaction, fine sedimentary deposition and crystallization of sparry calcite during lithification. The above distribution of porosity is confirmed by the comparison of an isoporosity map of the Ante Creek Reef with Figures 9 and 10.

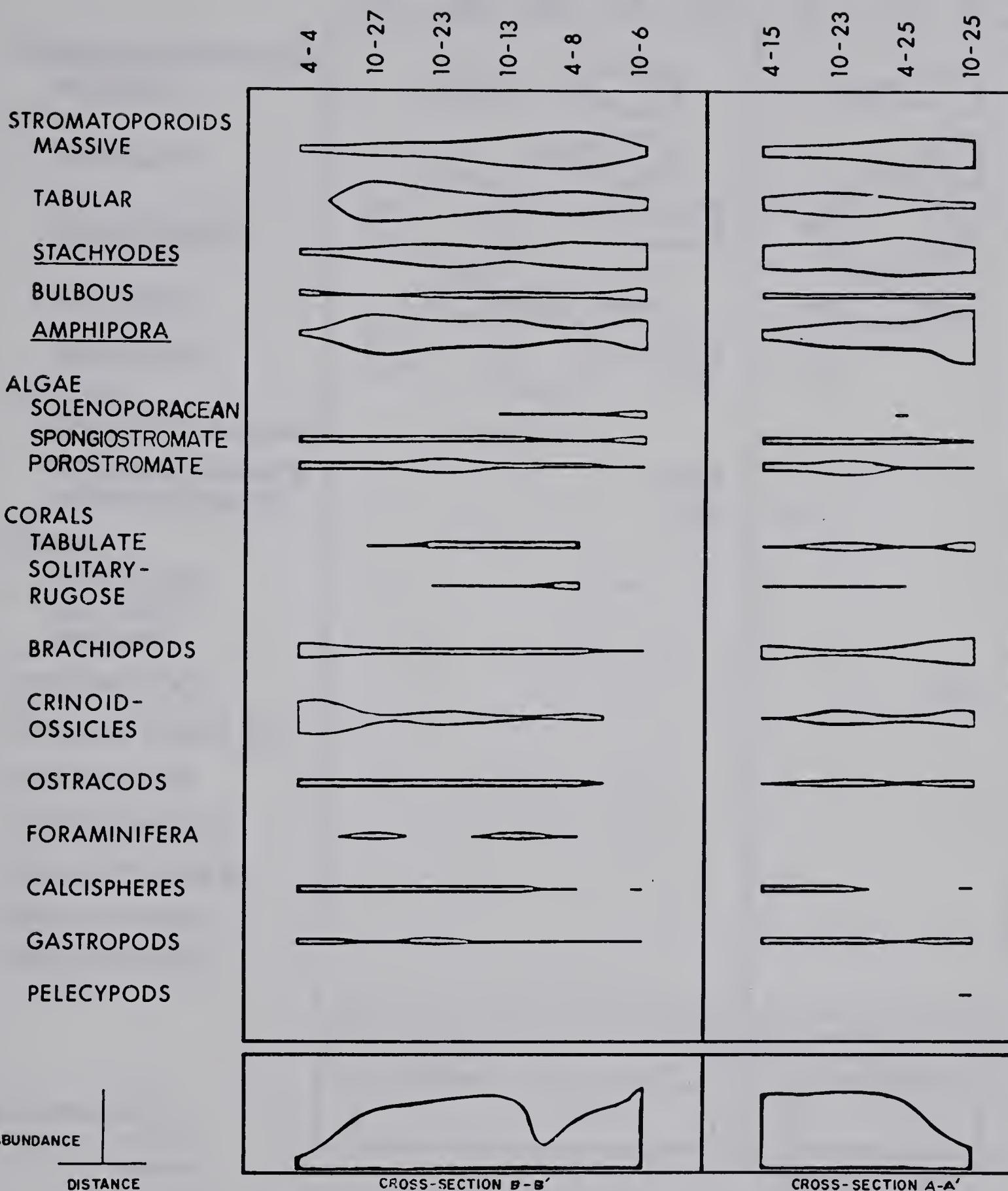
#### PALEONTOLOGY

Appendix 1 contains descriptions of the organisms encountered in the Ante Creek Reef study. This data was obtained from binocular microscope studies of the slabbed surfaces of ten cores as well as from detailed observations of thin sections and acetate peels. The physical characteristics, identifications, lithological and faunal associations, position on the reef as well as inferred environments are the aspects studied for each type of organism involved.

#### CHARTS OF FAUNAL DISTRIBUTION

Figures 6 and 7 show the distribution of fossil remains in the Ante Creek Reef. Figure 6 illustrates the over-all distribution of organisms within the individual cores studied. However, this type of

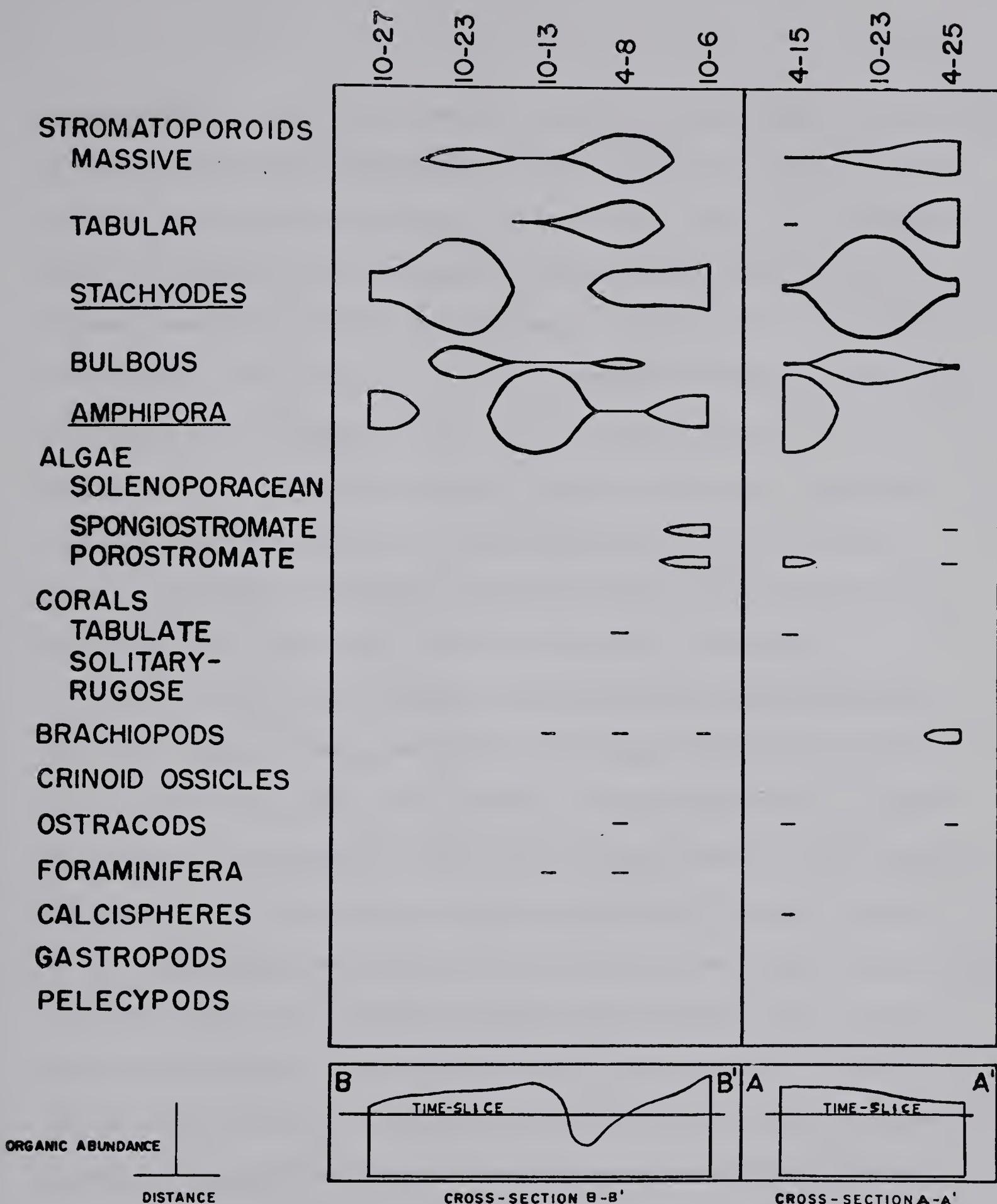




DISTRIBUTION OF ORGANISMS IN THE ANTE CREEK REEF COMPLEX

FIGURE 6





DISTRIBUTION OF ORGANISMS ACROSS THE  
ANTE CREEK REEF AT A PARTICULAR  
TIME

FIGURE 7



diagram provides little information regarding environmental distribution. Little environmental interpretation can be made on the basis of which core has the greater percentage of a particular fossil type. Figure 6 does not indicate the relationships between single organisms or between communities of living organisms at a particular time during reef growth. Difficulties in the interpretation of Figure 6 are apparent in the Amphipora distribution in cross-section A-A'. Amphipora appears to be concentrated on the outer edge of the reef although a close inspection of the core proves this to be false. A higher percentage of Amphipora in the Dark Brown unit of core 10-25-65-24 W5M than in the other cores explains this discrepancy.

Figure 7 depicts the organic associations in a horizontal slice of a late stage of reef growth. This time-slice represents the surface of the reef over a short time interval. It was chosen so as to intersect the maximum number of facies with the most diverse fossil content. The results of such an examination are probably as reliable as those of the neontologist who maps biofacies distributions across the surfaces of modern reefs. On the basis of organic distribution alone, it can be seen from Figure 7 that the quiet-water protected area of the reef lay in the vicinity of Atlantic Ante Creek 4-15-65-24 W5M. The increase of massive, tabular and digitate stromatoporoids eastward of well 4-15-65-24 W5M denotes the proximity of the active growth zone of high turbulence. Digitate and bulbous stromatoporoids flourished on the reef-flat, although a small quantity continued into the back-reef. The high density of Amphipora, the presence of porostromate algae,



ostracods and calcispheres is indicative of the quiet lagoonal zone on the west side of Ante Creek. Brachiopods are located on the reef-edge in well 4-25-65-24 W5M. It was here that they were exposed to sufficient enough turbulence to provide the necessary nutrient supply. The occurrence of tabulate corals in the lagoonal environment is low and they can be considered as being fragments washed in from the active growth zone to the east. Modern corals require clean, well-aerated waters of normal salinity which are found in the turbulent zones of the reef. The abundance of tabular stromatoporoids in the reef-edge zone and the paucity of digitate stromatoporoids (Figure 7) in this area may indicate degree of turbulence and/or the successful dominance of one stromatoporoid type over the other in the competition for growth space. Probably the turbulence dictated which type of stromatoporoid would flourish at the expense of the other. Cross-sections A-A' and B-B' indicate an increase in the numbers of Amphipora with a decrease of other stromatoporoid types. The bulbous types tend to increase with an increase in the numbers of digitate forms, indicating either a preference for a similar type of environment or else a symbiotic type of relationship. Figure 7 suggests the main lagoonal zones to be in the vicinities of Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, Arco Ante Creek 10-6-65-23 W5M and Atlantic Ante Creek 4-15-65-24 W5M. The abundance of solenoporacean and spongiostromate algae at the southwest end of cross section A-A' indicates this to have been a quiet-water lagoonal area.

Figure 7 shows that an accurate picture of the reef morphology



at a particular time can be constructed by studying the distribution of organic constituents.

### PALEOECOLOGY

#### APPLICATION OF PALEOECOLOGICAL PRINCIPLES

##### GENERAL

Paleoenvironmental interpretations are difficult because the rock types studied represent the depositional environments existing after death of the organic constituents. Furthermore, the processes of diagenesis alter the deposited material until the characteristics of the original organisms or sediments may be barely recognizable. Close inspection of the depositional remnants will reveal whether or not the sediments and/or organisms are in situ or whether they have been transported.

Interpretation of organic and organic-sediment relationships involves the differentiation of area of habitat, area of death and area of burial. If the organism was sedentary then the first two locations will be coincident. If the skeletal remains have been transported as indicated by abrasion, disarticulation, current alignment, size and mass-sorting, then the locus of burial will differ from the locus of habitation. It is unlikely that all three locations will coincide if a vagrant benthonic, a nektonic or a planktonic organism is considered. Recognition of these three loci is useful in concluding whether a particular accumulation is a biocoenose or a thanatocoenose.



The members of a biocoenose have common characteristics as a result of adaptation to mutual environmental conditions such as temperature, light intensity and nature of the substratum. If an association of whole, delicately-structured fossil remains is observed embedded in a calcilutite, then a quiet-water biocoenose is indicated. The types of organisms and their adaptive traits are directly related to the physical chemical and organic features of the surrounding environment. If more than one type of environment is recognized from the organic remains then a thanatocoenose is represented.

#### ORGANIC ASSOCIATIONS IN ENVIRONMENTAL INTERPRETATIONS

In an environmental study it is necessary to recognize and identify in situ sessile benthonic organisms. These types of fossil remains are the most important indicators of paleoenvironments. Vagrant benthonic forms may provide information concerning nature of the substratum, water depth and salinity. Nektobenthonic, nektonic, planktonic and epiplanktonic organisms are largely free of the substratum and may be transported from one environment to the other during their life or after death. A large concentration of these types in any one location may indicate that they flourished in that area or that they were transported to this site of deposition by currents and waves. In the latter case the organisms will display physical alterations indicative of transportation e.g. disarticulation, abrasion.

#### SEDIMENT CHARACTERISTICS AS ENVIRONMENTAL INDICATORS

The sedimentary matrix surrounding the fossil material provides invaluable information about the sedimentary environment. If the



organic material is disarticulated, abraded and/or fragmented and the enclosing sediment is a laminated micrite then transportation of fossil remains and their eventual deposition in quiet water is concluded. A calcarenite sediment indicates a turbulent depositional environment. It is essential to first determine if the organic material is in situ then to examine the sediments for indications of the nature of the depositional environment. If an in-place accumulation is recognized from the fossils then the sedimentary matrix will not only be indicative of the depositional environment but also indicative of the life-environment. In the latter case the character of the substratum and the nature of the water conditions prevailing in the biotope may be concluded.

#### ECOLOGICAL FACTORS

According to Laporte (1968, Page 45) salinity, turbulence, water circulation, and character of the substratum are the main ecological variants affecting faunal distribution on the Bahama Banks today. Water depth, which includes the related factors of temperature, light intensity and turbulence, is considered of secondary importance because different types of communities may exist at the same water depth. The organic, physical, and chemical characteristics of the environment are inter-related so that no one factor is predominant in directing the development of organic communities. The variation in bottom relief and associated turbulence play a significant role in the distribution of organisms in the reefal environments.



Newell et al., (1959) considered the basin geometry (topography and hydrography) and basin energy (waves and currents) to be the two major features responsible for variations in environments on the Bahama Banks. Related to topography and hydrography are turbulence, circulation, salinity and nature of the substratum, each of these being interrelated. Related to the energy of the waves and currents are turbulence, circulation, turbidity, salinity and substratum. A change in any of these conditions may result in physical and/or chemical alterations in the environment. If the range of tolerance of a sedentary organism is exceeded then death will result.

Direct evidence of salinity, light penetration or oxygen content of the waters of the paleoenvironments is difficult to detect. However, the degree of turbulence is directly related to the growth form and physical wear of the organisms as well as the texture of the sediments. The occurrence of primary pyrite in the sedimentary matrix may indicate a restricted depositional environment. Radioactive isotope studies of the sediments may, in the near future, play a large part in assessing the chemical and physical properties of the reef environments.

#### RELIABILITY OF VARIOUS ORGANISMS AS INDICATORS OF ENVIRONMENT

##### GENERAL

The high quality of organic preservation in the Ante Creek Reef Complex facilitates the study of organic and sediment-organism relationships. Secondary dolomitization is best developed in the inter-organic matrix and rarely within the fossil structures. However, a low organic diversity at the species level limits the study of species differentiation through environmental pressures e.g. adaptation of morphology within



a species due to chemical and/or physical changes. This low diversity may be a result of poor initial preservation, for according to Newell in Laporte (1968, Page 75), "For a coral reef environment....only 50-75 species will be fossilized out of a possible 3000." It is difficult to estimate the extent of the population of soft-bodied organisms which have not been preserved. Kornicker and Boyd (1962) in their study of the Alacran Reef of the Campeche Banks found that the most abundant species on the reef are those without preservable hard parts. The only evidence of fauna with non-preservable hard parts in the sediments is in the form of bioturbation effects and ichnofacies. Organisms of this type exert a profound influence on the type, rate, location and alteration of sedimentary accumulations. Furthermore, failure to identify species may be an additional factor in decreasing the diversity.

Many of the assumptions that have been made in the field of paleoecology are circular in reasoning. Certain fossil material may provide valuable information concerning environmental conditions; however, the nature of the surrounding sediments and related organic constituents may have been employed to support the validity of the given fossils in constructing the physical, organic and chemical life-environment.

#### STROMATOPOROIDS (EXCLUDING AMPHIPOROIDS)

Sessile benthonic organisms buried by sediments in situ best reveal conditions of the biocoenose. Stromatoporoids being sedentary and benthonic are reliable indicators of water turbulence and depth. Fisch-



buch (1962, 1968) suggested that certain groups of stromatoporoids were able to adapt to varying degrees of turbulence. Stromatoporoid coenosteal shapes are not diagnostic properties of particular species or even genera, however, they do provide indications of energy conditions of the environment. Thus, it is not necessary to identify specimens as to genera or species in order to describe conditions in which they lived. In reference to stromatoporoids, Galloway (1957, Page 400) stated, "they probably lived in a clear, shallow-moving water of tropical to subtropical environment." He also suggested that stromatoporoids were adjusted to annual seasonal changes in environment. The texture and composition of the enveloping sediment, the position of these organisms in the reef structure and the comparison of environmental characteristics with those of modern coral growths indicate that the stromatoporoids inhabited a shallow, warm-water clear marine environment. In the Ante Creek Reef the occurrence of stromatoporoids increases where the bituminous-argillaceous content of the sediments decreases. If the dark brown to black color of the Dark Brown unit limestones reflects turbid conditions of the depositional environment, then it would appear that stromatoporoids flourished under clear-water conditions e.g. in the Light Brown unit.

Because of their hemispherical shape and large size, the massive types (Plate 1, Figures 1 to 8 and Plate 2, Figures 1 to 4) appear to have withstood the high energy surf and are considered to have thrived in the surf zone. Figures 6 and 7 show that the massive stromatoporoids are concentrated on the reef-edge. An increase in the massive



nature of skeletal framework with increased water turbulence has been observed in corals (Lowenstam, pers. comm., 1968) and algae (Jamieson, 1967). The reef owes its wave-resistant nature, major topographic features and, in part, its porosity and dolomitization to the massive stromatoporoids. As well as developing separate bodies within the reef framework, the massive stromatoporoids commonly encrust other stromatoporoids, skeletal fragments of all origins and may be the major constituents in stromatoporoid-algal consortia. The main difficulty in interpreting the ecological niche of the massive stromatoporoids is deciding whether or not they are in growth position in the drill core. Evidence of abrasion is not easily detected on the outer surface of the massive stromatoporoid. Large fragments can be recognized only by their curved laminae. Environmental interpretations made by the writer corroborate those of Galloway (1957), Lecompte (1959), Klovan (1964, Page 35), Murray (1966, Page 16) and Fischbuch (1968). However, Fischbuch (1968) dispensed with the term 'massive' and referred to them as 'subspherical'. The writer prefers to apply 'subspherical' to the bulbous forms as it is more expressive of their shape.

Another type of stromatoporoid in the Ante Creek Reef is the bulbous form. Recognition of the large samples is subjective because a narrow drill core will not show the full extent of the bulbous coenosteum. Among the specimens observed in this study are two distinct types: one in which the initial growth area appears to have been close to one side of the coenosteum and one in which growth was from a central point with the laminae developing outward. It appears as though there were two methods of coenosteal growth involved:

- 1) Development upward and outward from a base of attachment.



2) Development of pillars and laminae outward from a centre as the coenosteum was being rolled about on the substratum. The spherical shape and the apparent lack of an anchoring mechanism of the second bulbous stromatoporoid type are suggestive of certain forms of algal stromatolites described and classified by Logan (1961) in Shark Bay, Australia. However, the algal bodies have an internal structure of overlapping crescentic layers indicating alternating periods of quiet upward growth and inversion. Such overlapping laminae are not evident in the stromatoporoids suggesting consistant overturning of the coenosteum. Thus, the writer considers bulbous stromatoporoids to have grown while attached to the substratum as well as being rolled about in the turbulent zone. Either way, these forms could be carried by bottom traction to a site of deposition of low turbulence. This would account for their presence in the back-reef and lagoonal facies although the samples in the Ante Creek Reef show little wear. Murray (1966, Page 17), the first to describe this form, indicated the environment of growth to be shallow-water lagoonal. Because of the occurrence of in situ bulbous stromatoporoids with in-place tabular as well as massive stromatoporoids, the writer prefers to associate the former with deeper water conditions. The low numbers of bulbous stromatoporoids in the Ante Creek Reef leaves their use as environmental indicators in doubt.

There appear to be two predominating species of Stachyodes in the reefal accumulation: one which has internal structure similar to a large Amphipora, but branching in nature (Stachyodes thomasclarki Stearn, Plate 3, Figure 5) and one with a much closer-packed internal



configuration with the branches shorter and more rotund (Stachyodes constulata Lecompte). Certain specimens of these digitate stromatoporoids grow out of massive-looking encrusting bases, both with similar radiating internal configuration (Plate 2, Figure 4). Fischbuch (1968) found the greatest concentration of them to be in the back-reef and to a lesser degree in the fore-reef deposits. They are associated with a moderate to low turbulence by virtue of their semi-delicate structure and the fine grain size of the enclosing sedimentary matrix. Although many of the digitate stromatoporoid remains are fragmented in the Ante Creek material, the low degree of abrasion indicates little or no transportation, from their life-environment. The apparent abundance of digitate stromatoporoids on the reef-flat (Figure 7) is a result of the development of quiet-water areas related to reentrant channel activity. Klovan (1964, Page 39) suggested that they grew in turbulent to moderately turbulent water; however, the writer discovered several examples of in situ forms in fine lime mudstones, suggesting that digitate stromatoporoids inhabited quiet-water environments. Edie (1961, Page 283) and Murray (1966, Page 18) suggested a quiet-water origin but had little supporting evidence. These forms are termed 'branching' by Fischbuch (1968), but the writer prefers the term digitate because one cannot always observe the branching nature of these stromatoporoids in the core samples.

One of the most difficult coenosteal shapes to define in stromatoporoid studies is that of the tabular form. The writer considers this type to be of wide lateral extent and of small vertical



dimension (Plate 2, Figures 5 to 7 and Plate 3, Figures 1 to 3), the latter dimension ranging from 2 mm. to 5 cm. The coenosteal form is commonly termed 'laminar' because of the thin vertical dimensions and the horizontal nature of the laminae. Tabular stromatoporoids may be compared in habit to encrusting mats of coralline algae but tend to represent conditions of higher turbulence. This type is of a deeper water environment than the other forms of stromatoporoid and indicates moderate to low turbulence. The growth form suggests that tabular stromatoporoids were less wave-resistant than massive or bulbous types. However, their encrusting habit most likely contributed to their resistance to fragmentation. The high percentage of fragmented forms at the base of the Dark Brown unit appears to have been a result of transportation from a nearby location because of the low degree of abrasion exhibited. Perhaps the encrusting nature of the tabular stromatoporoids was the determining factor in their establishment of the first stromatoporoid colonies on the soft, muddy substratum. The horizontal nature of the coenosteal laminae permits the in-place forms to be useful in proving the horizontality of the carbonate deposit if the bedding is indistinct. The writer's conclusions agree with those of Murray (1966, Pages 16 and 17), Klovan (1964, Pages 36 and 37), Lecompte (1959) and Edie (1961, Page 283).

#### AMPHIPOROIDS

Amphipora grew abundantly in environments of low turbulence and moderate to high salinity. It was best suited to the quiet, highly



saline water of the lagoon and flourished there to the exclusion of most other sessile organisms.

The writer was unable to observe either branching of Amphipora or the presence of any form of holdfast, suggesting that this enigmatic fauna may have existed as a mat of criss-crossed tubular-shaped growths. The picture that Fischbuch (1968, Figure 3.2) illustrates is one in which the Amphipora inhabit the quiet restricted waters of the reef complex, attached to the fine grained substratum by delicate thread-like stems which would provide little support for the weight of the upper portion of the body. Jamieson (1967) does not consider Amphipora to belong in the group Hydrozoa, but to be related to algae. However, the internal arrangement of vacuities closely resembles that of the stromatoporoids. Amphipora is one of the most definitive indicators to use in dividing the reef into environmental facies. By employing in-place massive stromatoporoids and Amphipora the paleoecologist can gain a primary indication of turbulent versus quiet-water and deep versus shallow-water environments.

Two distinct sizes of Amphipora occur in the Ante Creek Reef. The small-diameter form is located at the base of the Dark Brown unit in very dense bituminous-argillaceous limestone and is profuse to the exclusion of all other fossils. A typical specimen has a diameter of 1 to 2 mm. and a length up to 2 cm. (Plate 3 Figure 6). In the upper part of the Dark Brown unit, and scattered throughout the Light Brown unit in thin intervals, is the larger form of Amphipora that has a typical diameter of 2 to 6 mm. and length of up to 3 cm.



(Plate 3, Figures 7 and 8, Plate 4, Figures 1 and 2). Both of these varieties appear to be unbranched, and have the typical tubular external shape and meandering internal vacuities. It is possible that the increase of size may have been the result of increased turbulence and/or decreased turbidity. If so, then both types could be of the same species. The diameter of canals appears to be proportional to the coenosteal diameter.

Euryamphipora is present at several localities in the Ante Creek Reef (Plate 4, Figure 3). This fauna appears as though a small diameter Amphipora had been stretched out in all lateral directions. The location of the samples in the Ante Creek Reef indicates that Euryamphipora preferred the less turbid environment of the late stages of the Dark Brown unit deposition. Murray (1966, Page 19) refers to Euryamphipora not by its name but by the phrase '... growth form of Amphipora ....'. Also, Euryamphipora is acknowledged by Leavitt (1966) and Fischbuch (1968).

#### ALGAE AND CALCISPHERES

The aquatic plants known as algae grow in modern seas in very shallow water, usually less than one-hundred feet in depth. Ager (pers. comm., 1968) made a study of recent algal deposits on the Trucial Coast of the Persian Gulf in an area of supratidal salt-encrusted flats called 'sabkha'. These areas of growth are in the mid-tide level and tend to form mucilagenous adhesive mats. Research done by Logan (1961) in Shark Bay, Australia, confirms that algal bodies (in this case stromatolites) thrive in very shallow, warm, clear



water of normal to high salinity. Algal material is very rare in the present study, possibly because of its delicate nature and consequently its poor preservation. The writer agrees to some extent with Jamieson (pers. comm., 1968) that we observe only a minute quantity of the algal remains that once inhabited these Devonian reef environments.

In Ante Creek, the Parachaetetes-type of solenoporacean red algae (Plate 4, Figures 4 to 6) appears to have a framework capable of withstanding at least minor turbulence. It occurs rarely with tabular and massive stromatoporoids. According to Johnson (1961, Page 39), the red algae are "the structurally highest group of algae". Edie (1961, Page 282) suggested that all organic life in the reef depended on algal growth at one time or another. He was drawing an analogy between the Devonian algae and modern plants, the latter forming the bases of the neoecological food pyramids. The red algae are capable of secreting lime to form a rigid skeletal framework thus enabling them to be preserved. Solenoporacean algae are rare not only in the Ante Creek Reef but also in all reefs of Swan Hills age. The writer suggests that this paucity is a result of their low numbers in the reef community and not a result of poor preservation. Because solenoporacean algae are associated with in situ digitate stromatoporoids, the environment of habitation was probably of moderate to low turbulence. A highly turbulent environment is suggested by Edie (1961, Page 282), Johnson (1961), Brown (1963, Pages 178-180) and Murray (1966, Page 22).



The most numerous type of algae in the reef are the porostromate forms (blue-green) including the genus Girvanella which consists of a mat of interwoven tubules, each tubule being less than 1 mm. in diameter (Plate 4, Figures 7 and 8). These tubules occur in micrite which was little disturbed either during or after deposition. The algal tubes probably served as sediment binders, the intertwined filaments providing an effective sediment baffle as do modern Thalassia-type plants. The delicate structure of these mats reflects the lack of turbulence in the area of habitation. Probably this framework was broken up by periodic storms, thus accounting for the presence of fragmented tubules with in-place massive stromatoporoids. Because preservation of such fine structures would be difficult and considering the numerous occurrences of this algal type throughout the reef, it appears to have been one of the most abundant organisms in the Ante Creek Reef. Brown (1963, Page 180) suggests a very shallow environment for porostromate algae because the algal mats would be close to the water surface in order to receive the required amount of sunlight.

Another type of blue-green algae identified in the reef is the spongiostromate form which constitutes the rounded to sub-rounded bodies known as oncolites (Plate 5, Figures 1 and 2). These structures encrust central nuclei of organic and inorganic origin. As this central object rolls around in the high energy environments the algal body is able to construct a poorly defined skeletal framework about the outer surface. The cellular tissue of these oncolites is usually



poorly preserved and the accumulation of material about the centre has the appearance of accreted layers of lime mud. The encrusting algae in this study is similar to that described by Johnson (1961, Page 210) as Spongiostroma; however, the writer was unable to distinguish tubules in the internal structure. Brachiopods appear to have provided the loci for growth of this algal type. These oncolites were easily transported to any part of the reef. The writer regards this laminated and granular type of structure to be of the "family" Spongiostromata and not of the family Porostromata to which Girvanella belongs. Ginsburg (1955, Page 129) has found that modern oncolites grow in water from 1 to 6 feet deep. Murray (1966, Page 23) considers a similar yet less definite environment for these algae but does not acknowledge the "family" Spongiostromata.

Many of the lagoonal micrites have poorly defined undulatory laminations, commonly containing moderate quantities of sparry calcite. This structure is similar to algal lamination but no definite framework is evident (Plate 5, Figure 3). The writer suggests that much of this lagoonal material was deposited as a result of algal activity, the framework of this algae being rarely preserved. An attempt was made in this study to remove algal filaments from the most likely-looking laminated muds by dissolving the limestone in hydrochloric acid. However, no filaments remained in this residue.

Environmentally significant and possibly related to the algae are the calcispheres which may represent the reproductive phases of certain algae. Calcispheres are scattered throughout the Ante Creek



Reef structure but tend to be most numerous (still less than 1 percent) in the micrite muds. It is possible, however, that the calcispheres were not preserved in other areas of the reef, because they were easily fragmented in turbulent water conditions.

## CRINOIDS

The stem ossicles are the most commonly preserved crinoid structures in the Devonian reefs of western Canada. Calyx plates are a rare occurrence. However, in the Silurian reefs of Illinois (Lowenstam, pers. comm., 1968), the entire crinoid skeleton is often preserved. Perhaps, after the death of this organism only a small amount of turbulence was sufficient to disarticulate the arms, calyx and stem. The calyx plates may have been extremely fragile and thus were rarely preserved, or perhaps the proportion of calyx plates to ossicles was relatively small. An accumulation of similar-sized abraded stem ossicles indicates transportation and sorting (weight and size); however, the ossicles observed in the Ante Creek Reef are, for the most part, poorly sorted and not eroded. Crinoid remains occur in unit 'A' (Figures 9 and 10) in an argillaceous-bituminous dark brown micrite (Plate 6, Figure 1) and are thought to be indicative of deep, quiet water. There are also isolated pockets of crinoidal limestone in the upper levels of the reef. The writer prefers to interpret both of these crinoidal deposits as having resulted from transportation of crinoidal material from the fore-reef environment because of the good to moderate sorting and because of their association with calcarenites. According to Edie



(1961), echinoderms are normally associated with the deeper fore-reef deposits where the water turbulence is low and the black bituminous muds are deposited. Crinoids are not characteristic of lagoonal sediments, perhaps because of the high temperature and salinity of such a restricted environment. Crinoid ossicles can be relied upon as environmental indicators only when combined with other organic and inorganic criteria.

#### CORALS

Both the tabulate and rugose types of coral are rare in the Ante Creek Reef, the dominant organism being the stromatoporoid. The solitary rugose types (Plate 5, Figure 5) are rare and are of little value as environmental indicators if not combined with other organic remains or sediment characteristics. The lack of corals in this Middle to Upper Devonian reef is in contrast to the abundance of such forms in modern reefs. This suggests the evolution of reef complexes as a whole throughout geologic time where new ecological niches become available with a change in conditions such as sea-level and are gradually taken over by new fauna. The fauna itself evolves with old lines becoming extinct and new lineages appearing. The tabulate corals of Ante Creek (Plate 5, Figures 4 and 6) are rare and occur at scattered locations in the Light Brown and Dark Brown units. The specimens near the top of the Light Brown unit are difficult to distinguish from Stachyodes and Amphipora. A shallow warm-water environment of habitation cannot always be assumed for the corals, for Teichert (1958) found that they could inhabit deep



cold water. However, in the case of Ante Creek there is a wide variety of evidence supporting a shallow-water reef environment. It is difficult to conclude whether or not the corals in the Ante Creek Reef are in situ; however, abrasion and fragmentation are low enough that one may assume in most cases that they are in-place. Edie (1961, Page 283) concluded that both rugose cup corals and the tabulate thamnoporoid types inhabited deep-water environments as well as the quiet waters of the back-reef. Murray (1966, Page 20) concluded that the reef flank or fore-reef slope were the most suitable ecological niches; however, lack of supporting evidence renders this interpretation questionable.

#### BRACHIOPODS

Brachiopods are useful tools in paleoecological research, especially for denoting quiet or turbulent conditions. If they have the pedicle and brachial valves intact and attached then it may be assumed that these specimens are in situ and were deposited under quiet conditions (Plate 5, Figure 7). If the surrounding sediments are fine grained, then the quiet-water conclusion is further substantiated. If the valves are disarticulated then some turbulence is suspected because the valves will not voluntarily open when the organism dies. If the single valves are oriented with the convex side down, then it indicates that the valves probably settled in quiet water after having been disarticulated during transportation. The tendency is for the centre of balance to orient the valve in this manner. If the convex side of the valves is directed upward or if the valves are at a variety of



orientations and are fragmented as well, then active transportation to a turbulent site of deposition is indicated. Further supporting evidence may be obtained from the sediments and associated fauna. Also, if brachiopod valves are oriented with the long dimensions parallel and they are roughly the same size, then current sorting has probably occurred. The majority of the specimens of the Ante Creek Reef were disarticulated and not oriented in any particular manner, suggesting a turbulent site of deposition (Plate 5, Figure 8). A few whole shells were observed embedded in micritic limestones. Edie (1961, Page 283) concluded that brachiopods and crinoids inhabited muddy, quiet environments of variable depths. He noted that neither organism is found in lagoonal sediments. Because the atrypids in the Ante Creek Reef occur with crinoids, tabular stromatoporoids and gastropods, the writer suggests a shallow to moderately deep environment of habitation with little turbulence. Murray (1966, Page 20) notes the occurrence of articulate brachiopods with crinoid debris.

#### OSTRACODS

The nektonic-planktonic habit of this organism may account for its wide distribution throughout the Ante Creek Reef. During storm periods, the small, light-weight ostracods were probably transported to a variety of reef environments (Plate 6, Figure 2). Because ostracods are similar in habit to the modern brine shrimp, several authors suggest that they inhabited waters with higher-than-normal salinity. However, modern ostracods can be found in fresh, brackish as well as salt water. The occurrence of ostracod valves in micrite



is probably a result of preservation, not environmental selection, and it is likely that these free-swimming scavengers roamed all over the reef. Murray (1966, Page 21) assumed that ostracods inhabited waters of slightly high salinity because of their occurrence with Amphipora in fine laminated muds. The writer concludes that ostracods indicate little about the reef environments.

#### MOLLUSCS

Molluscs (Plate 3, Figure 7) occur only rarely in the reef deposits and are associated with argillaceous limestones, crinoids, brachiopods and ostracods (Plate 6, Figure 3). The gastropods in the Ante Creek Reef were vagrant organisms which had a wide range of tolerance for salinity, temperature, depth and turbidity. The modern gastropods can be found in shallow lagoonal areas as well as in the basinal deeps. Most specimens exhibit little or no abrasion or fragmentation indicating that either they are all in situ or that they had resistant shells. Edie (1961, Page 283) concluded that gastropods inhabited semi-stagnant environments with normal-marine and highly saline water. The writer concludes that the gastropods in this study inhabited deep to shallow and turbulent to quiet water, similar to the habitat of their modern relatives.

#### MICROFOSSILS (EXCLUDING OSTRACODS)

Foraminifera and a chambered organism of questionable origin are rare in the Ante Creek Reef (Plate 6, Figures 5 and 6). These occur in fine calcarenites and micrites probably as a result of



good preservation in a quiet environment of deposition. The writer attempted to extract conodont material from various facies within the reef but was unsuccessful.

#### PALEOENVIRONMENTAL INTERPRETATIONS

##### ROCK TYPES

Twenty rock types were distinguished in the Ante Creek Reef by employing the classification discussed earlier in the thesis. Each name represents a comprehensive short-hand description of the rock types including composition abundance and size range of the major constituents. Allochems i.e. pellets, intraclasts, oolites and skeletal material as well as micrite are combined in a single rock name. The rock types are included in the following list:

Skeletal micritic calcirudite

Amphiporoid calcilutite

Micrite

Stromatoporoid calcilutite

Skeletal-pelletal calcirudite

Stromatoporoid micritic calcirudite

Amphiporoid-dolomitic calcirudite

Pelletal-stromatoporoid calcarenite

Stachyodes calcirudite

Stromatoporoid-pelletal calcirudite

Stachyodes-amphiporoid pelletal calcirudite

Pelletal calcarenite



Stachyodes-pelletal calcirudite

Pelletal-amphiporoid calcarenite

Skeletal calcilutite

Pellsparite

Amphiporoid micritic calcirudite

Brachiopod-sparitic calcirudite

Stromatoporoid-brachiopod calcirudite

Amphiporoid-pelletal calcirudite

## FACIES DIVISIONS

The foregoing rock types are representative of different sedimentary environments that in turn approximate the environments of habitation of the in situ organisms. In Figures 9 and 10 the reef has been divided into a number of environmental facies which closely parallel the wide variety of environments within the Ante Creek Reef during its development. Each facies is recognized primarily on the basis of organic content (mainly sedentary organisms) and secondarily on the basis of lithologic composition and texture. If the sediment (not including in situ fossil material) is considered environmentally significant, then it may be used as the primary indicator. The writer suggests that a new term be proposed to refer to the different paleoenvironmental types, namely, 'paleoenvirofacies'. These are not physical entities although they bear the same names as the rock types. Paleoenvirofacies reflect the sedimentary and biological aspects that characterize the environments present in the developing



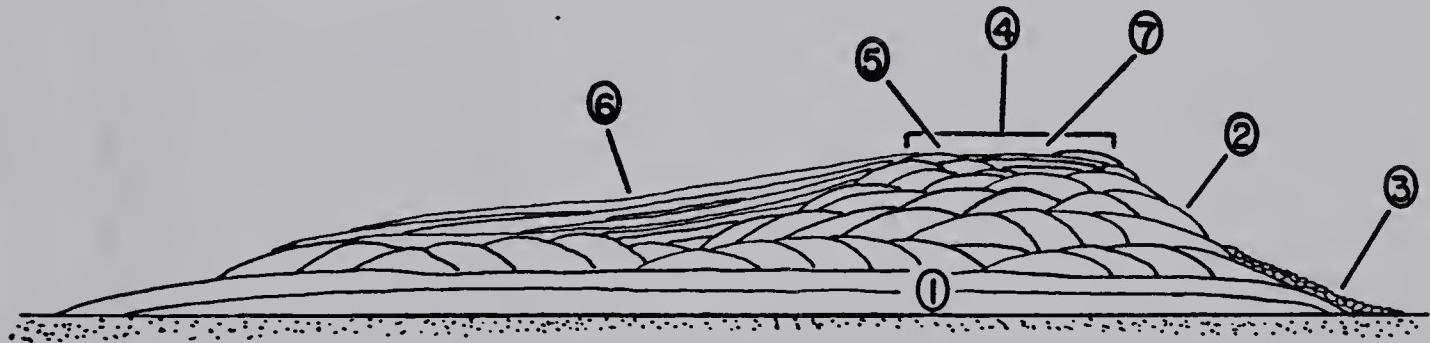
reef. Like biofacies or lithofacies, paleoenvirofacies have both vertical and lateral dimensions and grade vertically and laterally into one another. The term 'origofacies' of Vassoevich (1948) in Teichert (1958, Page 2735) is defined as the primary sedimentary facies, however, the writer prefers to use a more explicit term such as paleoenvirofacies. The expression 'ecological facies' could be applied here but its present usage is in marine neoecology, not paleoecology.

In Figures 9 and 10 the contacts between different horizontal paleoenvirofacies are drawn as feather-edges, whereas those between vertical environmental changes are depicted as horizontal lines. Modern reefs develop laterally as well as vertically, resulting in lateral facies contacts which may be horizontal or may dip towards the basin or towards the shallower shelf region. However, in this thesis, the major development of the paleoenvirofacies is considered to be in a vertical direction. The limitations imposed on a reef study such as that of Ante Creek by core examinations from widely spaced wells render any conclusions concerning the direction of dip of paleoenvirofacies difficult.

The major paleoenvironments of the Ante Creek Reef are illustrated in Figure 8. These include the fore-reef slope or reef-talus zone, the reef-front, the reef flat, the back-reef or lagoon-edge, the lagoon proper and small lagoonal pockets on the reef-flat. These were the main geomorphological areas of the reef throughout its development. The paleoenvirofacies represented by the rock names are actually sub-facies of these major reef facies depicted in Figure 8.



SCHEMATIC DIAGRAM of the ENVIRONMENTS  
ASSOCIATED with the ANTE CREEK REEF  
COMPLEX



- ① Platform
- ② Reef-Front
- ③ Fore-Reef Slope
- ④ Reef-Flat
- ⑤ Lagoon-Edge
- ⑥ Lagoon Proper
- ⑦ Small Lagoonal Pockets

FIGURE 8



60

HOMESTEAD ANTE CK. PAN AM ANTE CK. B-2 PAN AM B-8 ANTE CK.  
IO-23-65-24-W5M 4-25-65-24-W5M 10-25-65-24-W5M A'

A ATLANTIC ANTE CK.  
4-15-65-24-W5M

(WBG)

(UBL)

(SHF)

(LB)

(DB)

(G)

(R)

(N)

(O)

(P)

(X)

(Z)

(J)

(H)

(U)

(V)

(W)

(A)

(B)

(C)

(D)

(E)

(F)

(G)

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B

PAN AM C-1 ANTE CK.  
4-4-65-24 WSM

PAN AM B-5 ANTE CK.  
10-27-65-24 WSM

HOMESTEAD ANTE CK.  
10-23-65-24 WSM

ATLANTIC ANTE CK.  
10-18-65-24 WSM

PAN AM D-1 ANTE CK.  
4-8-65-23 WSM

ARGO ANTECK  
10-6-65-23 WSM

61

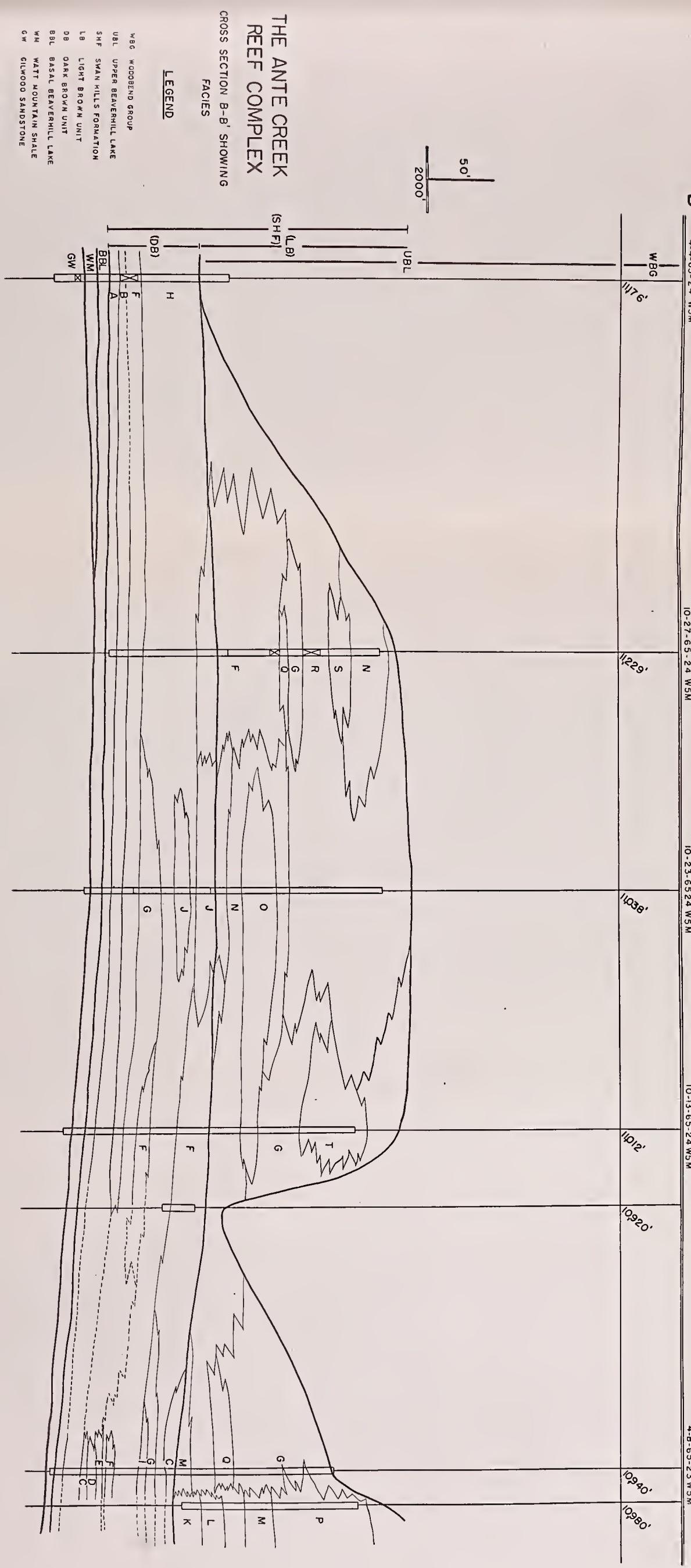


FIGURE 10



In the subsequent list, each paleoenvirofacies is given a letter 'A' through 'Z' and ' $\alpha$ ', ' $\beta$ '. Each paleoenvirofacies is named after the rock type that characterizes it. One rock type may represent more than one paleoenvirofacies where the content of the rock is altered, so as to affect the particular environmental interpretation but not the rock name. The principal criteria for recognizing each paleoenvironment is inferred in the rock name; the minor criteria follow the rock name in order of importance. An alteration in these minor criteria may be sufficient, in certain cases, to differentiate paleoenvirofacies although the rock name remains the same. In the energy-level designation of the paleoenvirofacies some of the descriptive elements have been repeated so as to indicate which criteria were important in the energy selection. The following list includes the paleoenvirofacies of the Ante Creek Reef.

A   Skeletal micritic calcirudite - sedimentary boudinage, brachiopods, crinoid ossicles.

Shallow water, quiet, basinal; high bituminous-argillaceous content, boudinage a result of compaction of soft lime muds.

B   Skeletal micritic calcirudite-tabular stromatoporoids, brachiopods, crinoids, gastropods, ostracods, solitary corals.

Fore-reef to reef-flat, semi-rough to medium turbulence; high percentage tabular stromatoporoids, low percentage massive stromatoporoids, crinoid ossicles, tabulate corals,



whole gastropods.

C Amphioporoid calcilutite - bulbous stromatoporoids, gastropods, crinoids, brachiopods, porostromate algae.

D Micrite - brachiopods, Amphipora, calcispheres, porostromate algae, ostracods.

E Stromatoporoid calcilutite - digitate stromatoporoids brachiopods, solenoporacean algae, ostracods.

C,D,E Lagoonal facies, channels perpendicular to the reef-front.

C to D - commence with a semi-restricted environment containing Amphipora brachiopods, a few crinoid ossicles, then restricted conditions during the deposition of D with ostracods, calcispheres, brachiopods and porostromate algae being present. D to E - semi-agitated water, intermediate between quiet and agitated environments with digitate stromatoporoids Amphipora, solenoporacean algae, ostracods, brachiopods.

F Skeletal-pelletal calcirudite - porostromate algae, intraclasts, Amphipora, sucrosic dolomitization.

Moderately quiet-water lagoon with bituminous-argillaceous material predominating; Amphipora, brachiopods, high percentage of porostromate algae, pellets, ostracods, gastropods.

G Stromatoporoid micritic calcirudite - massive, digitate, tabular, bulbous stromatoporoids, Amphipora, porostromate algae, ostracods, pellets, intraclasts.

Moderate energy with massive and tabular stromatoporoids, few Amphipora, clay and porostromate algae predominating,



bulbous stromatoporoids, ostracods, digitate stromatoporoids, pellets at south end of reef.

- H Skeletal micritic calcirudite - massive, digitate and bulbous stromatoporoids, porostromate algae, Amphipora, pellets, clay, ostracods, corals; greatest percentage of porostromate algae (10%) in well # 10-13 (mid-reef), corals at south end of reef. A highly diversified facies with pellets throughout, and spongiostromacean algae in the northern region of the reef.

Moderately shallow water, high energy with massive stromatoporoids, Amphipora and digitate stromatoporoid fragments, ostracods, corals, sparry calcite, pellets.

- I Micrite - pellets, porostromate algae, coral fragments; pellets grading into micrite.

Lagoonal, shallow, quiet-water with micrite, pellets, corals (transported), porostromate algae.

- J Skeletal micritic calcirudite - digitate stromatoporoids, Amphipora, Euryamphipora, porostromate algae, pellets, intraclasts, ostracods.

Medium to low energy, one grade higher in energy than lagoon environment with digitate stromatoporoids, Amphipora, Euryamphipora, porostromate algae, pellets, intraclasts, ostracods.

- K Amphioporoid-dolomitic calcirudite - intraclasts, pellets, massive, digitate and bulbous stromatoporoids.

Lagoon-edge slightly higher salinity, shallow quiet water with Amphipora, secondary dolomitization, trace of digitate,



bulbous and massive stromatoporoids.

- L Pelletal-stromatoporoid calcarenite - Amphipora, digitate stromatoporoids, intraclasts, sparry calcite (birdseye structure), gastropods.

Lagoon-edge slightly higher energy than 'K', moderate turbulence, shallow with Amphipora, Stachyodes, intraclasts, birdseye calcite, gastropods.

K to L - Represents evolution from a semi-restricted lagoon to more turbulent water.

L to N - Represents evolution back to lagoonal type.

- M Stachyodes calcirudite - massive and tabular stromatoporoids, Amphipora, dolomite, brachiopods, pale brown to white in color. Post lagoonal, intermediate energy tending toward high energy, probably outer edge of reef-flat with lagoon behind, with Stachyodes, laminar stromatoporoids, brachiopods.

- N Stromatoporoid-pelletal calcirudite - massive stromatoporoids,

Stachyodes, Amphipora, pellets, bulbous stromatoporoids, sucrosic dolomite, sparry calcite, medium to high porosity.

Moderately high energy, reef-flat to reef-front with

Amphipora, fragments - slightly back of fore-reef edge, partially protected, pellets swept into sheltered area; massive stromatoporoids and Stachyodes in growth position.

- O Stromatoporoid-pelletal calcirudite - digitate stromatoporoids pellets, intraclasts, ostracods, porostromate algae, brachiopods,



solitary corals at top of facies, moderately leached and dolomitized at base.

Quiet-water lagoonal, slightly turbulent with Amphipora, digitate stromatoporoids, pellets, intraclasts, corals, brachiopods, ostracods; coral fragments (solitary rugose) may have been washed in during storms; digitate stromatoporoids and porostromate algal tubes appear to be in growth position.

P Stachyodes-amphiporoid-pelletal calcirudite - solenoporoid, coating, and mat algae, intraclasts, sparry calcite with birdseye structure, moderate porosity.

Quiet-water lagoonal, less energy than 'O' with high percentage of pellets, Amphipora, algae, birdseye structure, and algal coating indicating some turbulence, Still some periodic turbulence at 'P' with digitate stromatoporoids in situ and birdseye structure; only 15% digitate stromatoporoids large gastropods, thamnoporoid corals.

Q Pelletal calcarenite - sparry calcite, bulbous stromatoporoids, disarticulated brachiopods, trace of dolomitization. Appears to be a bank of pellets and intraclasts swept into an area between massive stromatoporoids, at the south side of a lagoon ('O') with fragments of brachiopods and massive stromatoporoids, selective sorting is evident.

R Stachyodes-pelletal calcirudite - massive and bulbous stromatoporoids, sparry calcite, stylolites, thamnoporoid corals near top, buff to white, moderately porous.



Moderate to deep water, deepening toward the top of the reef as concluded from the presence of few pellets and corals highly agitated with Stachyodes, massive and bulbous stromatoporoids, pellets and intraclasts swept in, being well-sorted and cemented by sparry calcite.

- S Amphiporoid-pelletal calcirudite - digitate stromatoporoids, intraclasts, sparry calcite, micrite, moderate to high porosity, moderate dolomitization, Amphipora, leached. Lagoon-edge, moderate to low energy, just back of reef-flat with Amphipora, Stachyodes, pellets, intraclasts, latter probably swept in by moderately low energy currents because of the lack of large fossil fragments; Amphipora considered in-place since current would be too weak to carry them into the area.
- T Amphiporoid-pelletal calcirudite - intraclasts, tabular stromatoporoids, sparry calcite, micrite, ostracods. Semi-lagoonal, low energy environment, periodically swept by currents carrying tabular stromatoporoid fragments, pellets and intraclasts.
- U Pelletal-amphiporoid calcarenite - birdseye structure, porostromate algae, pyrite, spongiostromate algae, brachiopods, solenoporacean algae; well-laminated, calcite in bands. Lagoonal pelletal mud, very quiet-water, shallow, algae, Amphipora in-place, well-laminated, broken brachiopod valves washed in with concave sides of shells oriented randomly.



- V Skeletal calcilutite - bituminous-argillaceous material, sparry calcite, whole gastropods, fragmented ostracods, disarticulated brachiopod valves, massive and tabular stromatoporoids, crinoid ossicles, Megalodon specimen. Deep, quiet water, reef detritus, high clay content, sparry calcite, poorly sorted and abraded crinoid ossicles, brachiopod fragments with valves randomly oriented, stromatoporoid fragments.
- W Pellsparite - clay, gastropods, crinoid ossicles, brachiopods. Deep-water pellet bank with crinoid ossicles possibly in-place a low energy area of deposition.
- X Stromatoporoid micritic calcirudite - digitate and massive stromatoporoids, pellets, intraclasts, Amphipora. Reef-edge, very turbulent to moderately turbulent, with stromatoporoids in situ.
- Y Amphiporoid micritic calcirudite - clay, solid bitumen, pellets, porostromate algae. Lagoon-edge, shallow water, low energy, fauna may or may not be in growth position, algae not fragmented.
- Z Brachiopod-sparitic calcirudite - pellets, intraclasts, crinoid ossicles, pyrite, ostracods, thamnoporoid corals. Reef-slope detritus, well-sorted, current deposited in a relatively quiet, low energy environment, deep water, pellets, intraclasts, and relatively in-place crinoid ossicles, ostracods disarticulated, and thamnoporoid coral fragments.



α Stromatoporoid-brachiopod calcirudite - whole and disarticulated brachiopods, micrite sparite, crinoid ossicles, solenoporacean algae, gastropods, no dolomitization.

Fore-reef, deep to moderate depth, moderate energy, containing a high percentage of disarticulated and whole brachiopods, poorly abraded crinoid ossicles, whole solenoporacean algae and whole gastropods.

β Skeletal-pelletal calcirudite - disarticulated brachiopods, porostromate algae, pellets and intraclasts, Stachyodes, massive stromatoporoids, gastropods, micrite, sparite, Amphipora, ostracods.

Lagoon, moderate depth, low energy, slightly restricted with whole brachiopods, ostracods and gastropods, whole algae, Stachyodes, massive stromatoporoids and Amphipora.

The pattern of environments that is developed in Figures 9 and 10 is one of turbulent to sub-turbulent to quiet-water to sub-turbulent to turbulent vertically and laterally throughout the reef structure. The vertical configuration of facies in the various wells corresponds to the development of large reentrant channels shown in the structure contour and isopach maps (Figures 3 and 4). With a constriction of the reentrant channels by reef growth, barriers formed, reducing or totally impeding the high energy of the turbulent waters, causing small lagoonal pockets to form. A minor increase in sea-level would be sufficient to overrun the low barrier of the reentrant channels thereby allowing the energy-level to increase. Because of



## PALEOENVIRONACIES INTERPRETATIONS OF THE ROCK TYPES

ROCK NAME	TURBULENCE			DEPTH			POSITION ON THE REEF TYPES					
	H	M	L	D	M	S	FRS	RF	RFL	BR	LP	SLP
Skeletal Micritic Cr	X	X	X	X			X	X	X	X	X	
Amphiporoid Cl	X			X								
Micrite	X			X								
Strom Cl	X			X	X	X	X	X	X	X	X	
Skeletal Pelletal Cr	X			X			X	X	X	X	X	
Strom Micritic Cr	X	X		X			X					
Amphiporoid Dol Cr	X			X			X					
Pelletal Strom Ca	X			X			X					
Stachyodes Cr	X	X		X			X	X				
Strom Pelletal Cr	X		X	X			X	X				
Stachyodes Amph Pell Cr			X	X			X	X				
Pelletal Ca			X	X			X	X				
Stachyodes Pelletal Cr			X	X			X	X				
Pelletal Amphiporoid Ca			X				X					
Skeletal Cl		X	X					X				
Pellsparite	X		X				X	X				
Amphiporoid Micritic Cr		X					X				X	
Brachiopod Sparitic Cr		X					X					
Strom Brachiopod Cr	X		X				X				X	
Amphiporoid Pelletal Cr	X	X	X								X	

LEGEND

H	= High
M	= Moderate
L	= Low
D	= Deep
S	= Shallow
FRS	= Fore-Reef Slope
RF	= Reef - Front
RFL	= Reef - Flat
BR	= Back - Reef
LP	= Lagoon Proper
SLP	= Small Lagoonal Pocke's
Cr	= Calcirudite
Cl	= Calcilutite
Strom	= Stromatoporoid
Dol	= Dolomitic
Ca	= Calcarene
Amph	= Amphiporoid
Pell	= Pelletal

Table 4



the relatively low relief of the complex of environments, only a slight compaction of the reef or rising of the sea-level from any other cause would be adequate to open up these former channels. The principal lagoonal area of the reef lies west of the main reefal barrier and is well illustrated in Atlantic Ante Creek 4-15-65-24 W5M (Figure 9). Because of few control points it is difficult to locate the various paleoenvironments in the northern area of the reef body, where there seem to be abnormally thick and extensive lagoonal deposits on the edge of the reef. Future drilling between Pan Am C-1 Ante Creek 4-4-65-24 W5M and Pan Am B-5 Ante Creek 10-27-65-24 W5M, might confirm the interpretation in Figure 10, that is, a massive stromatoporoid turbulent zone capping the northern end of the reef. Another possibility is that the massive framebuilding organisms did not develop at this horizon. It is evident that to derive a more accurate picture of the reef internal structure, closer control points are necessary.

Table 4 illustrates the depth and turbulence indicated by the various rock types as well as their position on the reef.

#### REEF DEVELOPMENT

There are four main stages recognized in the depositional history of the Ante Creek Reef (Figure 11). Change in sea-level was the major influence on organic growth and sediment accumulation. It altered the energy-levels in the Ante Creek area as well as salinity, water temperature, degree of aeration, availability of food material



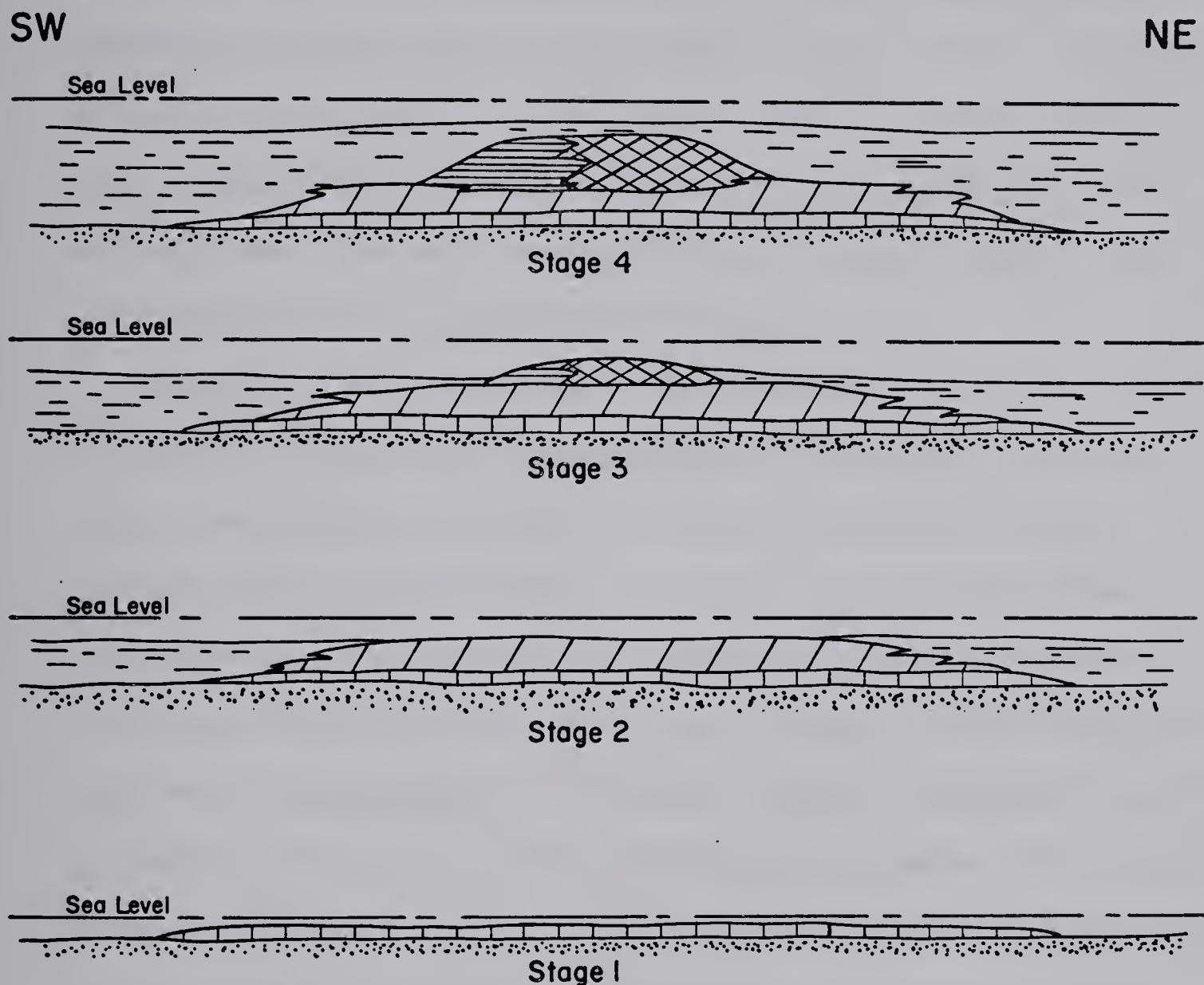
for the organisms and degree of turbidity. Changes in sea-level may have resulted from subsidence of platform sediments, basement faulting or eustatic alterations. The following stages of reef development were concluded from the paleoenvirofacies distribution and the geomorphological characteristics of the reef.

Stage 1. After deposition of the Watt Mountain Shale the coarse sand of the Gilwood Member was laid down in the Beaverhill Lake basin southeast of the Peace River arch. The Elk Point Group represents a period of shallow-water conditions with alternating mild transgression and regression during which shales, sandstones and evaporites were deposited. The basal Beaverhill Lake anhydritic shale was deposited during the gradual change of the sea from regression to transgression. As sea-level rose, the dark brown limestone deposition of Stage 2 was initiated.

Stage 2. When the environmental conditions e.g. temperature, depth, salinity, light, turbulence, turbidity and texture of the substratum were within the range of tolerance of the tabular stromatoporoid larvae, the biostrome was initiated. These larvae were probably scattered throughout the Beaverhill Lake sea, having drifted southward from the reefs north of the Peace River arch. After the biostrome had established itself laterally over the broad basal Beaverhill Lake platform, a gradual rise in sea-level changed the predominant growth of the biostrome from horizontal to vertical. Deposition of the off-reef sediments kept pace with the biostrome resulting in the familiar bank configuration (Klement, 1967). The color of the



## DEVELOPMENT OF THE ANTE CREEK REEF



### LEGEND

- [X] Active Biothermal Growth (Organic Reef)
- [H] Quiet - Water (lagoonal) Sediments.
- [/] Biostrome
- [Wavy Lines] Basinal Shale
- [Three Squares] Platform of Biostrome
- [Dotted Pattern] Gilwood - Watt Mountain

Figure 11.



dark brown biostrome is derived mainly from bituminous material and to a lesser extent from argillaceous sediment. The high content of solid bitumen may represent the remains of algae or abundant micro-organisms which flourished on this shallow-water mud bank. Crinoid stem ossicles are common in the initial stage of biostrome development. Because they represent a deep-water environment, the writer maintains that they were transported from the deeper basinal region onto the shallow mud bank by waves and currents.

Stage 3. A rise in sea-level and subsequent increased rate of transgression resulted in the development of the Light Brown unit. This actively growing bioherm was probably initiated at several elevated areas on the biostromal platform. Vertical development of the bioherm was more prominent than lateral development because of the rapidly deepening basin. The contact between the Dark and Light Brown units is gradational, with organic content increasing in abundance in the Light Brown unit. With rapid vertical expansion, the bioherm became a significant barrier to the waves and currents that approached the reef from the northeast. A quiet-water zone formed on the west side of this barrier resulting in lagoonal sedimentation. During this wave-resistant period, large reentrant channels characterized the eastern edge of the reef. These channels average 1 to 1.5 miles in width and may owe their existence to scouring by currents and/or waves. They appear to have been periodically restricted by barriers allowing the deposition of sediments and the growth of organisms characteristic of the lagoon. This would account for the paleo-



envirofacies configuration of Figures 9 and 10, where the vertical pattern of energy level is from turbulent to quiet to turbulent in wells penetrating the reentrant channels. Cross-section A-A' is parallel to the axis of the northernmost channel. The bioherm was sufficiently elevated above the surrounding sediments so as not to be influenced by terrigenous deposition. The lack of solid bitumen and the high content of sparry calcite in the Light Brown unit is probably a function of the turbulent environment that existed at that time.

Stage 4. This stage is characterized by the rapid upward growth of the bioherm and its subsequent inundation. As the water level rose rapidly, the bioherm grew upward and its increasing weight probably caused subsidence of the biostrome. The lagoonal deposit to the west of the bioherm became more extensive. With an abrupt increase in sea-level, reef growth was not sufficient to maintain the reef structure in the turbulent zone. The interpreted massive stromatoporoid-Stachyodes cap suggests that the wave-resistant organisms grew over the top of the reef as the transgressive sea restricted the area of the reef-top in the turbulent zone. There are no green shale markers of disconformable contacts within the Light Brown unit to indicate that the reef was exposed to subaerial erosion at any time. The persistence of massive framebuilders up to the Swan Hills-Upper Beaverhill Lake contact suggests that the bioherm was inundated during the rapid transgression, the latter which was responsible for deposition of the overlying upper Beaverhill Lake shale. This



carbonate unit is thicker over the Ante Creek Reef than over the Kaybob, Judy Creek, Carson Creek and Goose River reefs to the east. Also, the green shale unit, characteristic of most reefs of Swan Hills age, decreases in thickness from the Carson Creek Reef Complex westward, disappearing before reaching the Ante Creek Reef. The erosional breaks as indicated by the green shale intervals of the eastern reefs may be the expression of faults which raised the reefs above sea-level and resulted in their death. Ante Creek was probably located on a block which was down-faulted at the same time, was inundated then covered by a thick basinal shale interval. Deposition of the lower part of the upper Beaverhill Lake Shale would therefore be contemporaneous with the erosional interval in the Light Brown unit of the Kaybob--Goose River--Snipe Lake and Carson Creek--Judy Creek--Swan Hills reef trends. Because the thicknesses of the green shale marker and the upper Beaverhill Lake calcareous shales increase to the north and west, the writer suggests that the normal faulting was downward towards the northwest. Faulting is favoured over compaction because of the consistent deepening of the Beaverhill Lake basin to the northwest. Such epeirogenic activity would have been a common event in the evolution of the western Canada sedimentary basin (Martin, 1967).

#### UNIQUE PROPERTIES OF THE ANTE CREEK REEF

There are several characteristics of the Ante Creek Reef which differentiate it from other reefs of Swan Hills age, notably Goose River, Carson Creek North, Judy Creek and Swan Hills.



Geographically, Ante Creek is the westernmost reef of Swan Hills age with the exception of Northwest Ante Creek. As a result, Ante Creek provides an important link in tracing the early Upper Devonian paleogeography and paleoenvironments westward into the Foothills region.

Unlike a similar development in the Swan Hills, Carson Creek North and Judy Creek reefs, there is no well-defined coral bed at the base of the Dark Brown unit. Thamnoporoid fragments are scattered only rarely in specific cores at this horizon in the Ante Creek Reef.

The Watt Mountain Shale is developed in only one well at Ante Creek, Pan. Am. C-1 Ante Creek 4-4-65-24 W5M. However, a significant and more persistent interval (approximately 30 feet thick) is recognized in Carson Creek North. This green shale unit lies immediately above the Gilwood Sandstone at Swan Hills and was included in the basal Beaverhill Lake by Fong (1960).

Although anhydritic shale underlies the Swan Hills Formation at Ante Creek, the writer has termed this sequence the basal Beaverhill Lake not the Fort Vermilion Formation as acknowledged by Murray (1966) at Judy Creek, and Leavitt (1967) at Carson Creek North. This anhydritic shale is thin, has no anhydrite interbeds characteristic of the Fort Vermilion Formation and is gradional into the overlying Swan Hills Formation, and the underlying Watt Mountain Formation.

No green shale horizons nor an accompanying calcarenite reef-cap indicative of periods of subaerial erosion were recognized in the Light Brown biohermal unit. Definite green shale breaks are



characteristic of the Judy Creek, Carson Creek North and Goose River Reefs and thin in a westward direction. It appears, therefore, as though the Ante Creek Reef remained below water level throughout its development.

Upper Beaverhill Lake calcareous shales are thicker above the Ante Creek Reef than the equivalent lithology overlying the Goose River, Carson Creek North, Judy Creek and Swan Hills Reefs. This supports the theory that the Ante Creek Reef is located on a down-faulted block whereas the other reefs have a higher elevation as a result of upward faulting during the early Upper Devonian.

The Ante Creek Reef has a distinctive morphology. Rather than constituting a fringing reef surrounding central lagoonal sediments (a common configuration for Swan Hills reefs), it consists of an elongate massive framework portion fringing the east side of a carbonate bank. Lagoonal deposits are located on the west side of this reef-ridge as illustrated in Figure 11.

Thus, it can be seen that the Ante Creek Reef is sufficiently different in content and morphology from other reefs of Swan Hills age so as to be unique.

#### CONCLUSIONS

1. The Ante Creek Reef is a reef-fringed carbonate bank of low structural relief that rested on a shallow area of the Beaverhill Lake platform projecting northward into the Beaverhill Lake sea. The basal Beaverhill Lake anhydritic shale provided a platform for the



overlying biostromal Dark Brown unit which in turn supported the biohermal Light Brown unit. Surrounding and overlying this bioherm are argillaceous basinal shales and limestones.

2. Ante Creek provides an important link between the Kaybob - Goose River - Snipe Lake chain to the east and the Foothills region to the west. The thickness of upper Beaverhill Lake over Ante Creek suggests that (1) the Ante Creek Reef was downfaulted at the same time that the other reefs of Swan Hills age to the east were uplifted (2) and/or the Ante Creek area subsided by compaction of the biostrome (3) and/or the Beaverhill Lake platform was much further below sea level than it was in the east. The latter hypothesis is unlikely since nature of the fossil content and sediments is, for the most part, similar in all of the Swan Hills reefs. It appears as though deep Beaverhill Lake basin surrounded the Ante Creek Reef on the east, north and west sides. Little protection from active waves and currents was provided by the Sturgeon Reef platform to the northeast as indicated by the vigorous organic reef development and the deeply scoured reentrant channels on the reef-front. Deep channels in the Beaverhill Lake sea appear to have passed westward between the carbonate platform to the south and the Peace River arch to the north. The westward extent of this sea is not accurately known.

3. Although the rock classification of Leighton and Pendexter is adequate for distinguishing rock types, it leads to confusion in paleoenvironmental facies determinations.



4. The term 'paleoenvirofacies' is suggested for the lateral and vertical environmental changes within the major reef environments. It may be considered as the short form of 'paleoenvironmental facies'. Each paleoenvirofacies bears the name of the rock type which characterizes it.

5. The environment recognized from the rock samples is the depositional environment and from the characteristics of the depositional environment the life-environment of the organisms can be concluded indirectly. Diagenetic alterations of the depositional environment further impede an accurate interpretation of the life-environment.

6. Stromatoporoids provide the most informative indications of water turbulence and depth of any other organisms for two reasons: they are sessile benthonic in habit and their coenosteal shapes are indicative of the degree of turbulence. Algae are next in importance as environmental indicators; however, they are rarely preserved. Crinoid fragments, brachiopods, molluscs and forams provide information about paleoenvironments only if their in situ nature can be proven. The degree of fragmentation, the orientation of fragments and the texture of surrounding sediments prove to be accurate indicators of the depositional environment.

7. Reef development can be divided into four stages based on major organic and lithologic alterations. Stage 1 represents the accretion of the basal Beaverhill Lake platform, whereas stage 2 includes the vertical expansion of the broad biostrome. In stage 3 the massive



framework of the bioherm was initiated to the west of which developed a quiet-water area protected by the reef-ridge. Stage 4 includes the rapid vertical development of the bioherm and its eventual inundation and burial in basinal shale.

8. Several unique properties of the Ante Creek Reef differentiate it from other reefs of similar age: an absence of (1) green shale markers (2) a well-defined Fort Vermilion Formation (3) a basal coral unit (4) a persistent Watt Mountain shale; elongate shape with active reef growth only on the east side; it is the most westerly located reef of Swan Hills age; it has the thickest sequence of overlying upper Beaverhill Lake sediments of all the Swan Hills reefs.

9. The size of the 'reentrant channels' is governed by the well control. Further wells drilled on a closer spacing would probably reduce the size of the channels to the magnitude of surge channels.

With the development of the Northwest Ante Creek Field in 1968 and the most recent drilling proposals in the Side Lake area further to the northwest, it appears that Ante Creek is the most southeasterly located reef of a chain extending northwestward into the Beaverhill Lake basinal sediments. Further petroleum exploration to the northwest of Ante Creek will probably have favourable economic results.



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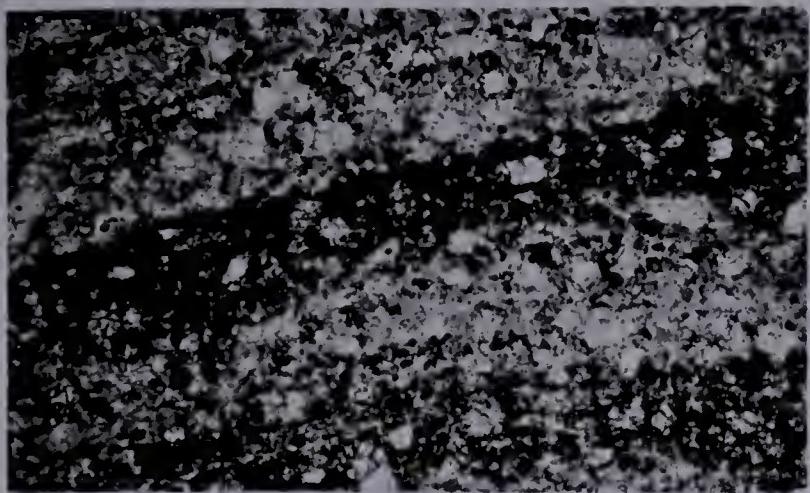
## PLATE 1

- Figure 1. Vertical section of Trupetostroma, massive coenosteum, in Dark Brown unit, thin section BCAC 10-13 # 8, X10; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,376 feet.
- Figure 2. Transverse section of Trupetostroma, massive coenosteum, in Dark Brown unit, thin section BCAC 4-8 # 3, X2.5 Pan. Am. D-1 Ante Creek 4-8-65-23 W5M, depth 11,356 feet.
- Figure 3. Vertical section of Trupetostroma, massive coenosteum, in Dark Brown unit, thin section BCAC 4-8 # 9, X2.5; Pan. Am. D-1 Ante Creek 4-8-65-23 W5M, depth 11,316 feet.
- Figure 4. Vertical section of Trupetostroma, thin section BCAC 4-8 # 9, X10; Pan. Am. D-1 Ante Creek 4-8-65-23 W5M, depth 11,316 feet.
- Figure 5. Vertical section of Trupetostroma, massive coenosteum, in Light Brown unit, hand specimen, X1.15; Pan. Am. D-1 Ante Creek 4-8-65-23 W5M, depth 11,218 feet.
- Figure 6. Vertical section of Trupetostroma, massive coenosteum, in Dark Brown unit, left half stained with alizarin red S, in a coarse calcarenitic argillaceous matrix, thin section BCAC 10-25 # 12, X2.5; Pan. Am. B-8 Ante Creek 10-25-65-24 W5M, depth 11,325 feet.
- Figure 7. Vertical section of Atelodictyon, massive coenosteum, showing well-defined pillars and laminae as well as numerous large voids, in Dark Brown unit, thin section BCAC 10-27 # 9, X2.5; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,562 feet.



Figure 8. Vertical section of Atelodictyon, thin section BCAC 10-27  
# 9, X10; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth  
11,562 feet.

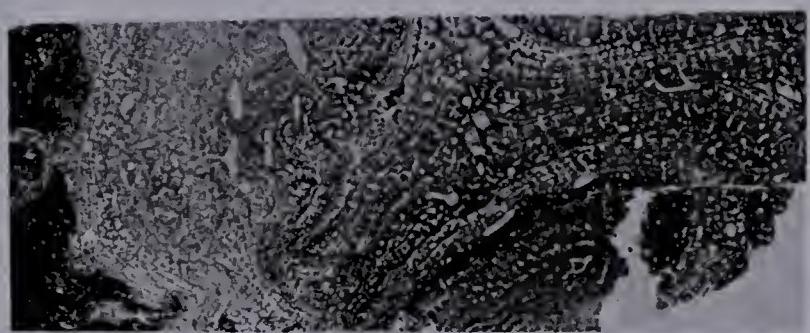




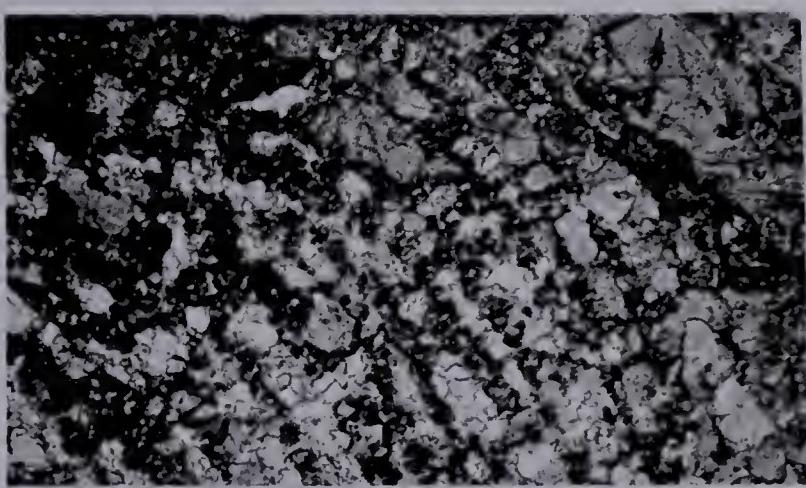
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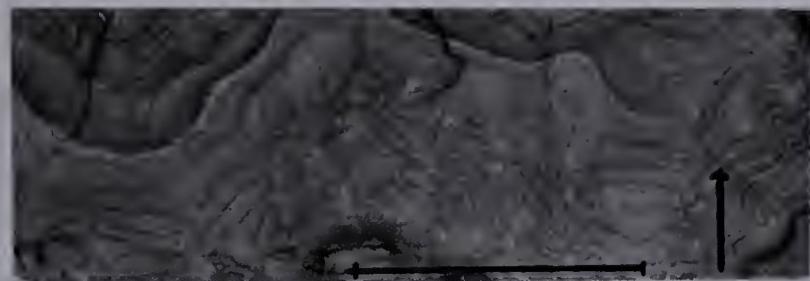
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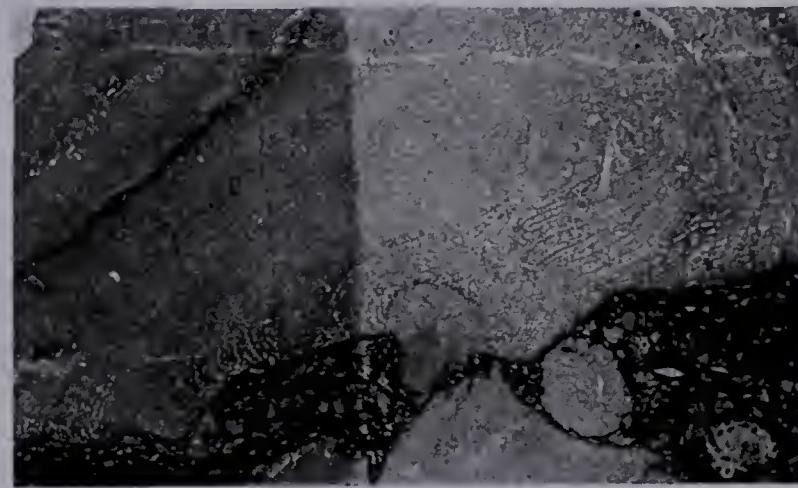
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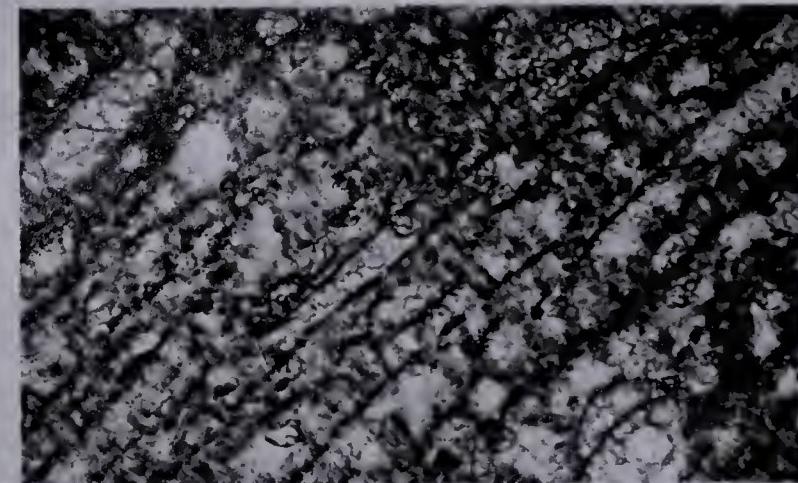
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PLATE I



## PLATE 2

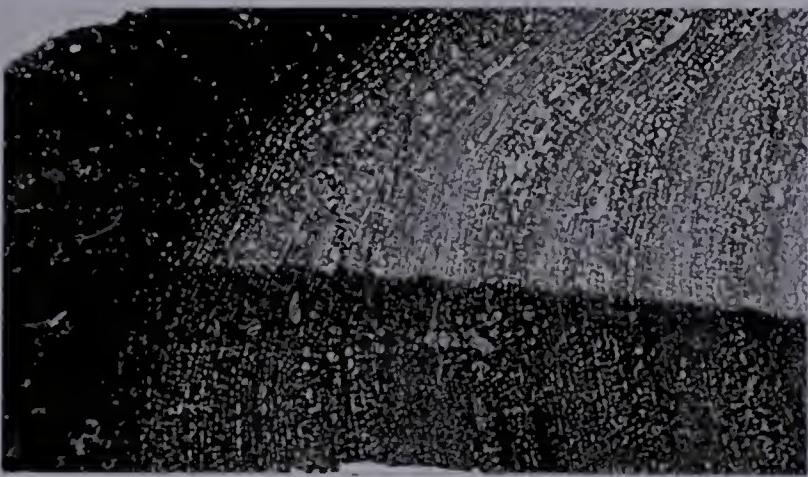
- Figure 1. Vertical section of Atelodictyon, massive coenosteum, well-developed pillars and laminae, and vacuoles, in a coarse skeletal calcarenite, bottom one-half of slide stained with alizarin red S, in Dark Brown unit, thin section BCAC 10-23 # 11, X2.5; Homestead Ante Creek 10-13-65-24 W5M, depth 11,401 feet.
- Figure 2. Vertical section of Atelodictyon, thin section BCAC 10-23 # 11, X10, crossed-nicols; Homestead Ante Creek 10-23-65-24 W5M, depth 11,401 feet.
- Figure 3. Massive to digitate stromatoporoid growth form in a coarse calcarenite matrix showing the growth of one massive stromatoporoid on another, a partially digitate coenosteum to the lower left, hand specimen, X1; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,291 feet.
- Figure 4. Massive growth form at base with digitate projections on top, stylolites divide the two coenosteal types, sugary-textured dolomite at top of picture, hand specimen, X1; Pan. Am. B-2 Ante Creek 4-25-65-24 W5M, depth 11,299 feet.
- Figure 5. Vertical section of Trupetostroma, tabular coenosteum, in lowest stromatoporoid-containing unit of the Dark Brown unit, left half of slide stained with alizarin red S, thin section BCAC 10-23 # 4, X2.5; Homestead Ante Creek 10-23-65-24 W5M, depth 11,441 feet.



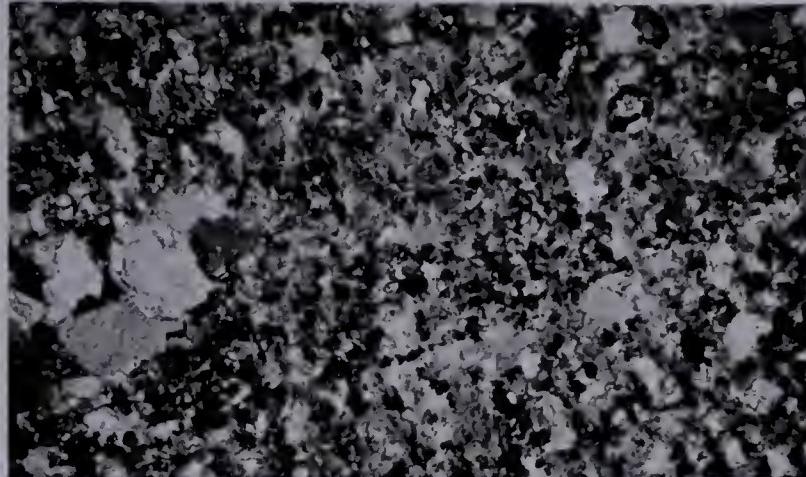
Figure 6. Vertical section of Trupetostroma, tabular coenosteum, in lowest stromatoporoid-containing unit of the Dark Brown unit, right half of slide stained with alizarin red S, central white areas containing sucrosic dolomite in a skeletal micrite, thin section BCAC 10-25 # 8, X2.5; Pan. Am. B-8 Ante Creek 10-25-65-24 W5M, depth 11,364 feet.

Figure 7. Vertical section of Clathrocoilona, tabular coenosteum, in lowest stromatoporoid unit of the Dark Brown unit, thin section BCAC 10-13 # 2, X2.5; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,423 feet.

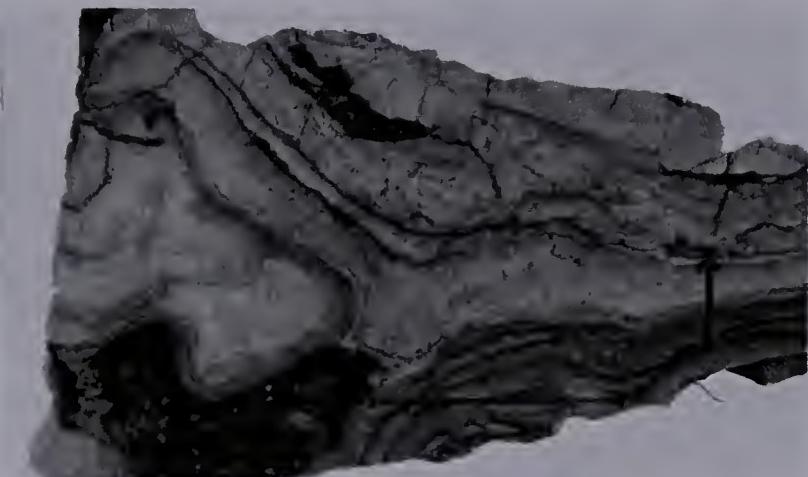




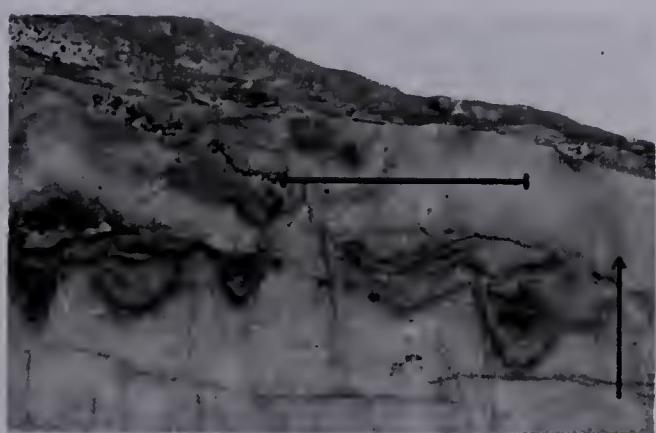
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PLATE 2



## PLATE 3

- Figure 1. Vertical section of Stromatopora, tabular coenosteum, lowest stromatoporoid unit of the Dark Brown unit, in fine to medium grained calcarenite, showing crinoid ossicles and brachiopod valves, thin section BCAC 10-27 # 3, X2.5; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,621 feet.
- Figure 2. Vertical section of Trupetostroma, tabular coenosteum, from facies 'B', left half of slide stained with alizarin red S, thin section BCAC 10-23 # 4<sub>2</sub>, X2.5; Homestead Ante Creek 10-23-65-24 W5M, depth 11,440 feet.
- Figure 3. Vertical section of Trupetostroma, thin section BCAC 10-23 # 4<sub>2</sub>, X10; Homestead Ante Creek 10-23-65-24 W5M, depth 11,440 feet.
- Figure 4. Transverse of Trupetostroma, digitate coenosteum, in a medium grained calcarenite at the top of the Dark Brown unit, thin section BCAC 4-8 # 8, X2.5; Pan. Am. D-1 Ante Creek 4-8-65-23 W5M, depth 11,316 feet.
- Figure 5. Stachyodes thomasclarki Stearn, digitate coenosteum, in a recrystallized and dolomitized calcarenitic matrix, at the base of the Light Brown unit, hand specimen, X1; Pan. Am. D-1 Ante Creek 4-8-65-23 W5M, depth 11,282 feet.
- Figure 6. Amphipora angusta Lecompte, small coenostea, in dark brown argillaceous-bituminous micritic matrix, in the base of the Dark Brown unit, thin section BCAC 10-23 # 6, X2.5; Homestead Ante Creek 10-23-65-24 W5M, depth 11,423 feet.



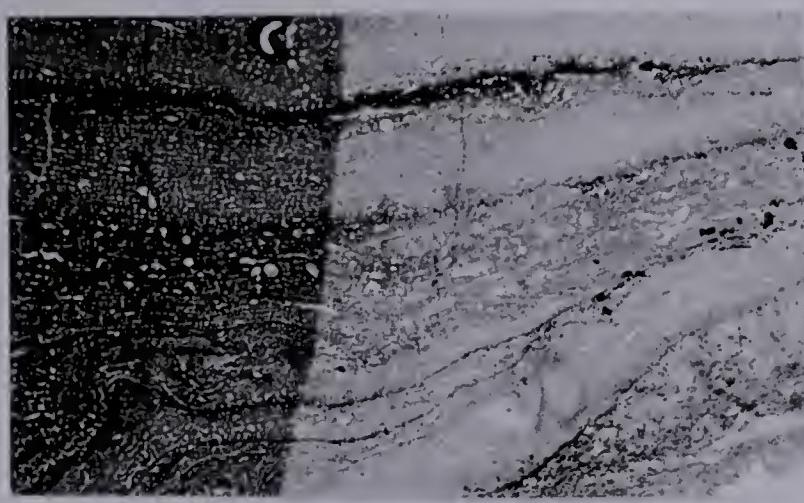
Figure 7. Amphipora angusta Lecompte, in light brown pellsparite containing recrystallized calcite and white dolomite, gastropod shell in centre, thin section BCAC 10-23 # 12, X2.5; Pan. Am. B-1 Ante Creek, 10-13-65-24 W5M, depth 11,335 feet.

Figure 8. Amphipora pervesiculata Lecompte, large central canal, in a pelletal micritic calcarenite within the Dark Brown unit, thin section BCAC 4-25 # 1, X10; Pan. Am. B-2 Ante Creek 4-25-65-24 W5M, depth 11,387 feet.

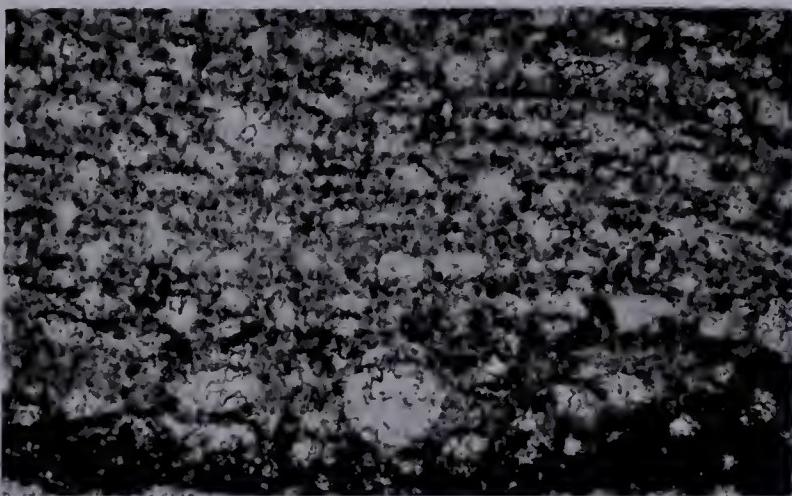




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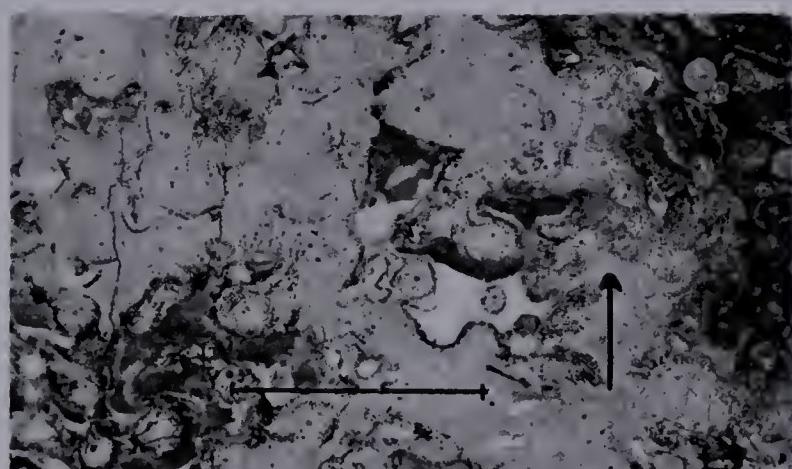
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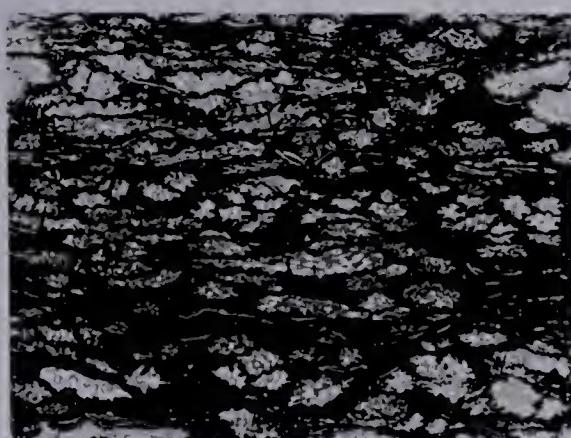
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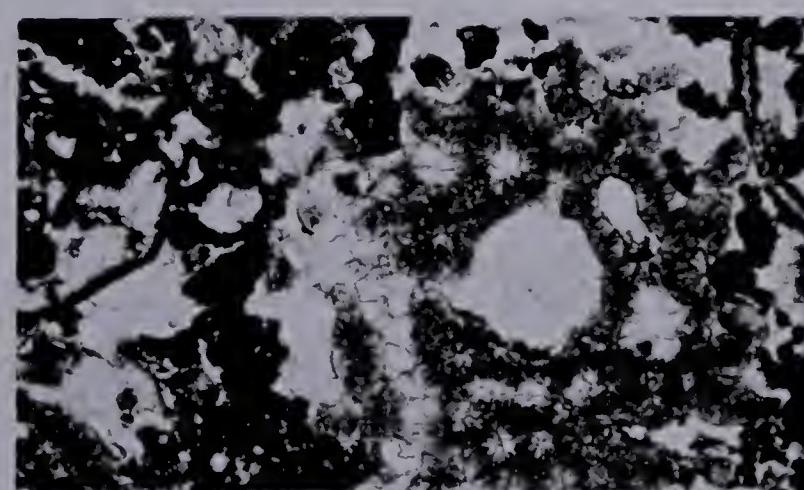
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PLATE 3



## PLATE 4

- Figure 1. Amphipora ramosa Phillips, in a fine grained calcarenite at the base of the Light Brown unit, left half of slide stained with alizarin red S, dolomite white, note low amplitude stylolites, thin section BCAC 10-23 # 15, X2.5; Homestead Ante Creek 10-23-65-24 W5M, depth 11,340 feet.
- Figure 2. Amphipora ramosa Phillips, entire slide stained with alizarin red S, sucrosic dolomite light grey to white, thin section 4-25 # 5, X2.5; Pan. Am. B-2 Ante Creek 4-25-65-24 W5M, depth 11, 339 feet.
- Figure 3. Euryamphipora and digitate stromatoporoid fragments in an argillaceous calcarenite at the top of the Dark Brown unit, hand specimen, X1; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,564 feet.
- Figure 4. Two growths of Parachaetetes, one showing digitate outgrowths, with Amphipora fragments, in a pellsparite matrix with large irregular blebs of sucrosic dolomite, at the base of the Light Brown unit, thin section BCAC 10-13 # 11, X2.5; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,336 feet.
- Figure 5. Parachaetetes, showing individual angular cells, thin section BCAC 10-13 # 11, X10; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,336 feet.



Figure 6. Cuneiphycus?, a red algae of uncertain affinities, showing laminations, in the Dark Brown unit, thin section BCAC, 10-13 # 7, X2.5; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,394 feet.

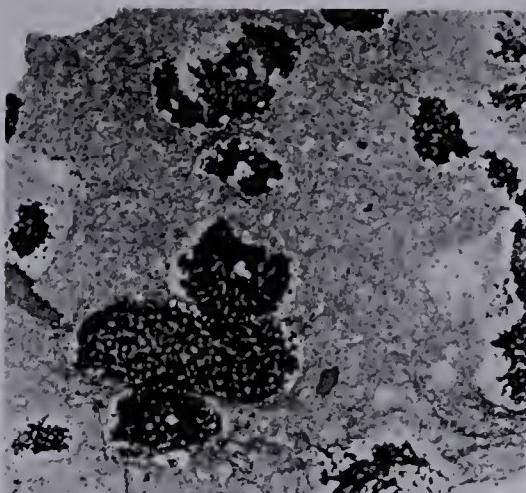
Figure 7. Unchambered, thin-walled tubes of Girvanella in a dark brown matrix of pellets and intraclasts, at base of the Dark Brown unit, thin section BCAC 10-13 # 3, X10, Pan. Am. 10-13-65-24 W5M, depth 11,413.

Figure 8. Girvanella tubes constricted at regular intervals to form bead-like strings, in a micritic limestone of the Dark Brown unit, thin section BCAC 10-13 # 5, X10; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,407 feet.





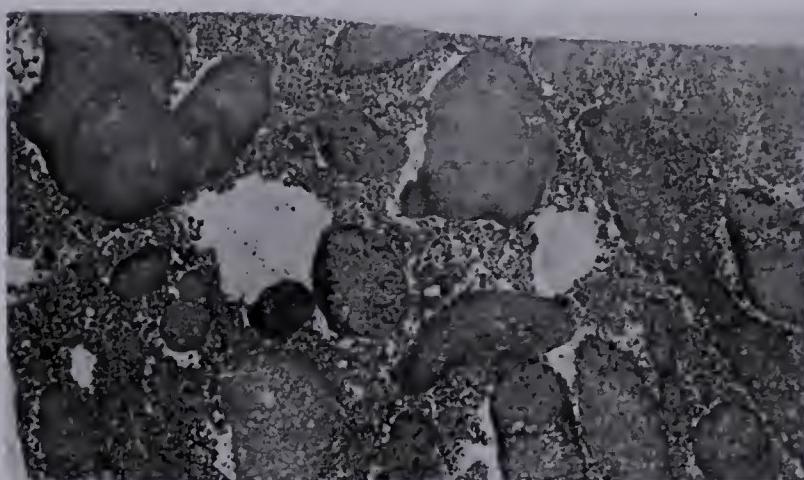
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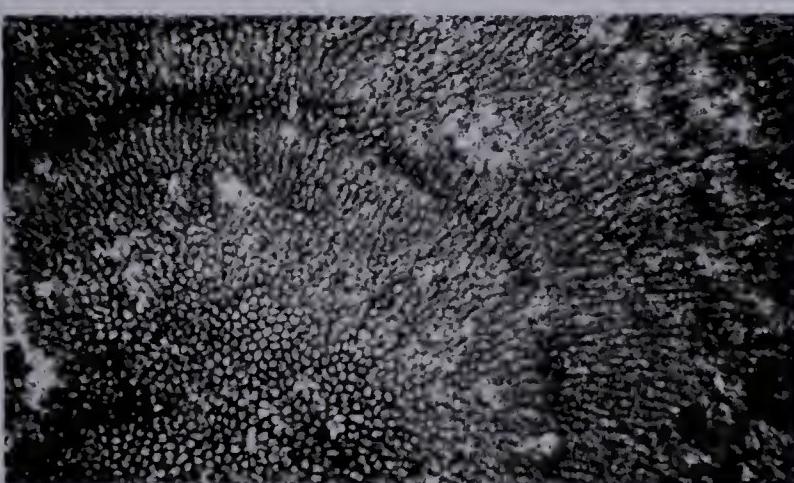
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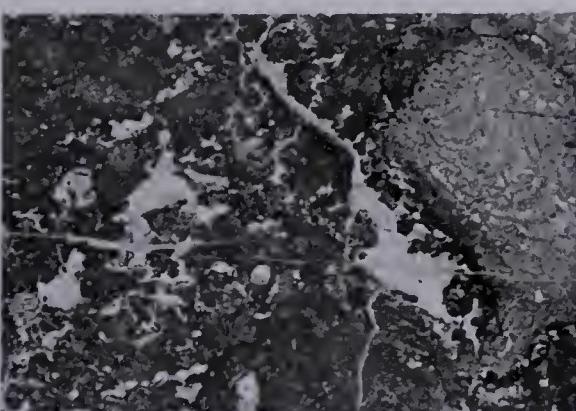
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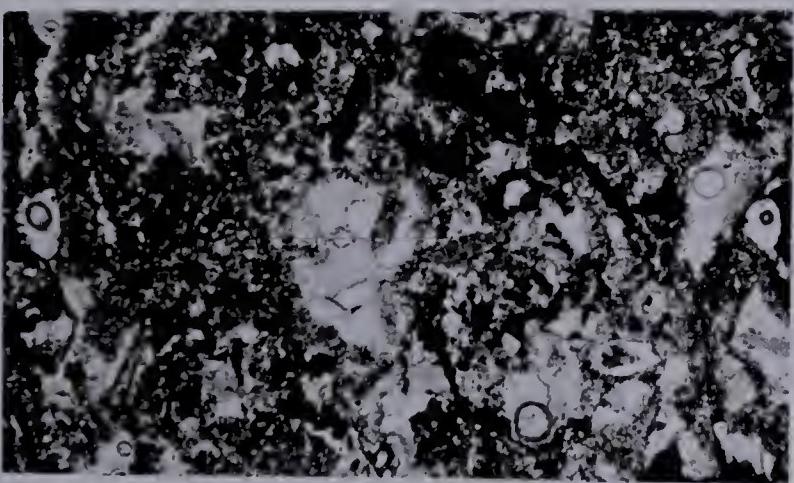
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PLATE 4



## PLATE 5

Figure 1. Spongistroma-type algal coatings around brachiopod fragments, associated with stromatoporoid fragments, in a medium to coarsely grained calcarenite of the Light Brown unit, hand specimen X1; Homestead Ante Creek 10-23-65-24 W5M, depth 11,304 feet.

Figure 2. Spongistroma-like algal coatings showing vague laminations, in the Light Brown unit, hand specimen, X1; Atlantic Ante Creek 4-15-65-24 W5M, depth 11,536 feet.

Figure 3. Laminated light brown limestone with high percentage of sparry calcite, micrite probably deposited by action of mat-type algae, open spaces left after the disintegration of the algal fibres, hand specimen, X1.15; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,426 feet.

Figure 4. Thamnopora, transverse and longitudinal sections, in a calcarenite at the top of the Light Brown unit, right half of the slide stained with alizarin red S, thin section BCAC 10-23 # 19, X2.5; Homestead Ante Creek 10-23-65-24 W5M, depth 11,234 feet.

Figure 5. Transverse-section of Alaiophyllum mackenziense Pedder in a fine to coarse grained argillaceous calcarenite, at the base of the Dark Brown unit, thin section BCAC 10-27 # 4, X2.5; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,619 feet.



Figure 6. Tangential sections of Thamnopora, massive type, in a pelletal calcarenite in the Light Brown unit, thin section BCAC 10-27 # 12, X2.5; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,438 feet.

Figure 7. Whole brachiopod shells in a bituminous-argillaceous calcilutite, associated with crinoid ossicles, central shell partially filled with micrite, upper portion filled by secondary coarsely crystalline calcite, indicates top, at the base of the Dark Brown unit, hand specimen, X.85; Homestead Ante Creek 10-23-65-24 W5M, depth 11,437 feet.

Figure 8. Brachiopod valve fragments showing fibrous calcite, calcarenite above, at the base of the Dark Brown unit, thin section BCAC 10-23 # 4, X10, crossed-nicols; Homestead Ante Creek 10-23-65-24 W5M, depth 11,441 feet.

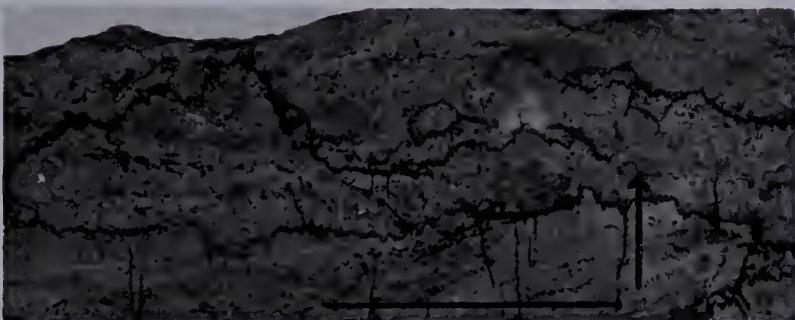




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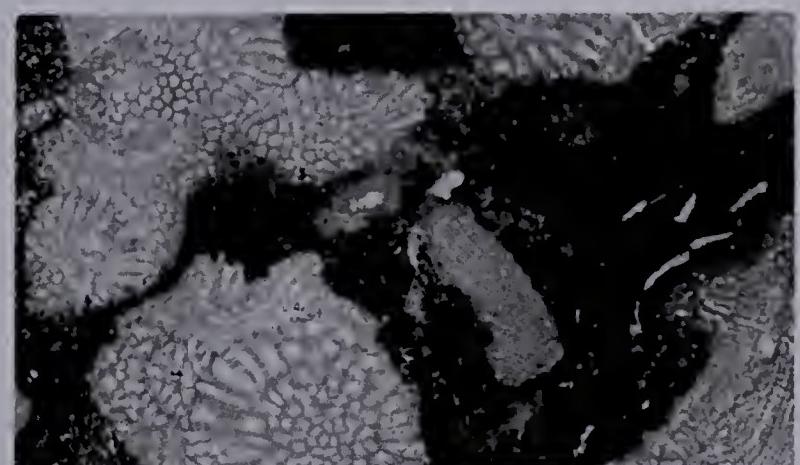
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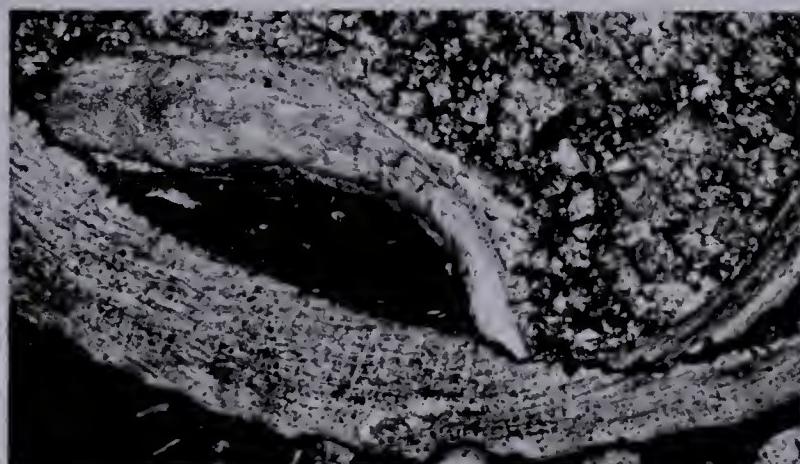
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## PLATE 5



## PLATE 6

- Figure 1. Skeletal micritic calcirudite containing crinoid ossicles and brachiopod fragments, right portion of the slide stained with alizarin red S, trace of foraminifera tests, in the basal facies of the Dark Brown unit, thin section BCAC 4-4 # 4, X2.5; Pan. Am. C-1 Ante Creek 4-4-65-24 W5M, depth 11,569 feet.
- Figure 2. Smooth-shelled leperditian ostracods, containing recrystallized calcite, at the base of the Light Brown unit, thin section BCAC 10-23 #16, X10; Homestead Ante Creek 10-23-65-24 W5M, depth 11,331 feet.
- Figure 3. Skeletal micritic calcirudite containing gastropods, brachiopods, foraminifera and ostracods, black color on brachiopods is pyrite, at the base of the Dark Brown unit, thin section BCAC 10-27 # 1, X2.5; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,627 feet.
- Figure 4. Skeletal micritic calcirudite containing crinoid ossicles, ostracod fragments and brachiopod fragments, right side of slide stained with alizarin red S, at the base of the Dark Brown unit, thin section BCAC 10-25 # 6, X2.5; Pan. Am. B-8 Ante Creek 10-25-65-24 W5M, depth 11,368 feet.



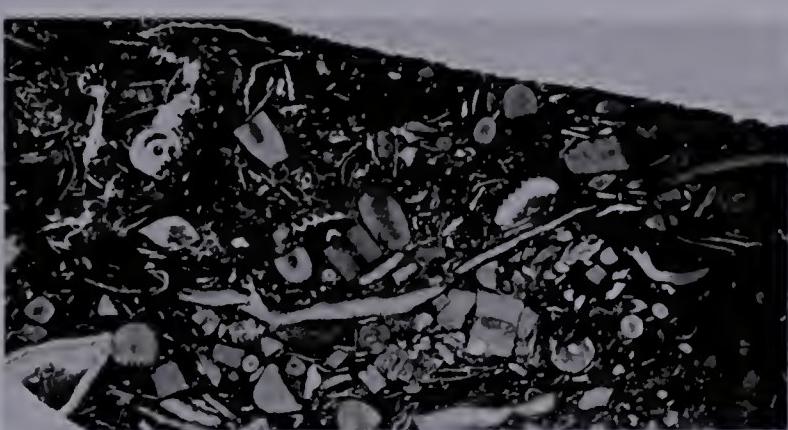
Figure 5. Pleurostomella-type of foraminifera, in centre, biserial to uniserial, in a medium to coarse grained pelletal calcarenite of the Dark Brown unit, thin section BCAC 10-27 # 7, X2.5; Pan. Am. B-5 Ante Creek 10-27-65-24 W5M, depth 11,586 feet.

Figure 6. Chambered organism of uncertain affinities, in centre of slide, in a pelletal calcarenite of the Dark Brown unit, sparry calcite crystals at bottom of slide, thin section BCAC 10-13 # 7, X10; Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, depth 11,394 feet.

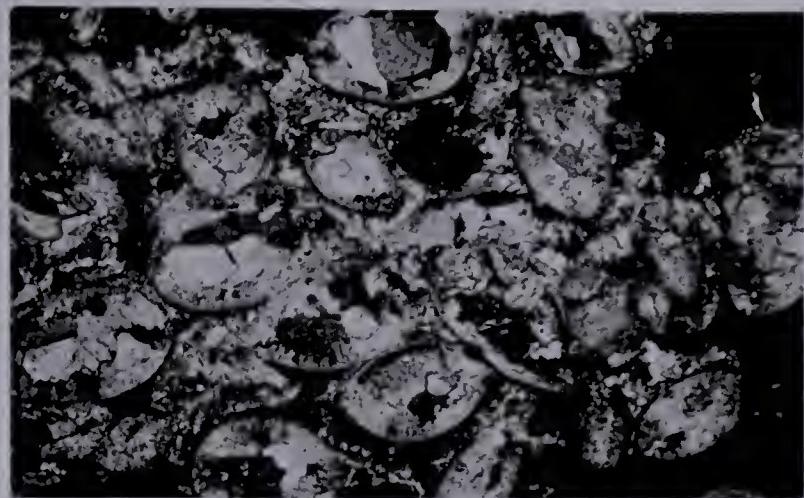
Figure 7. Gilwood Sandstone, crossed-nicols, showing the plaid-like feldspars, thin section BCAC 10-23 # 1, X10; Homestead Ante Creek 10-23-65-24 W5M, depth 11,460 feet.

Figure 8. Pink to buff sedimentary boudinage limestone with grey to green shale partings, termed Watt Mountain Shale, no fossils, hand specimen, X1.15; Pan. Am. C-1 Ante Creek 4-4-65-24 W5M, depth 11,594 feet.





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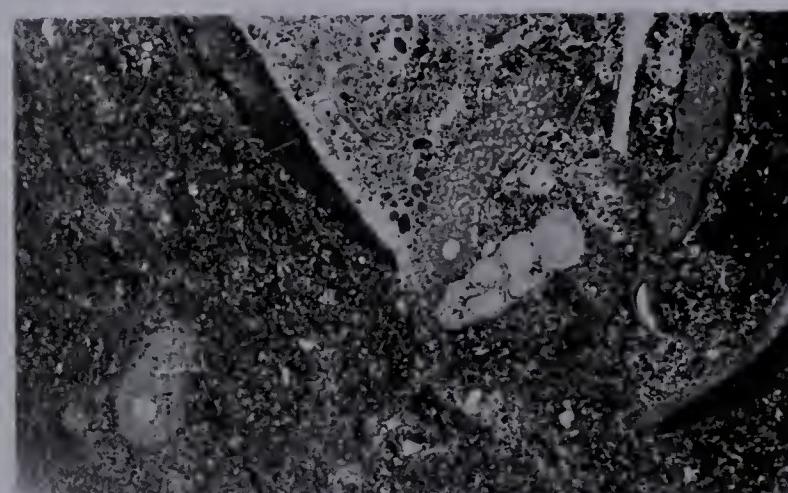
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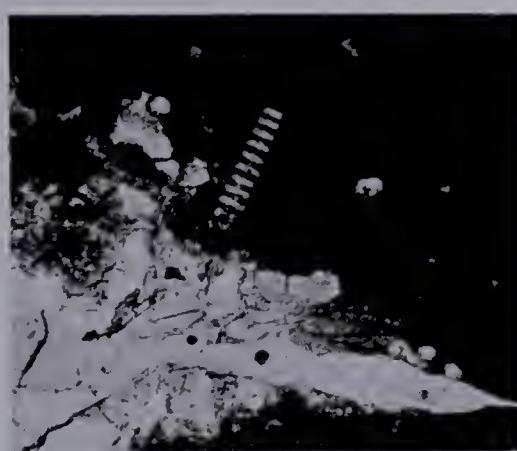
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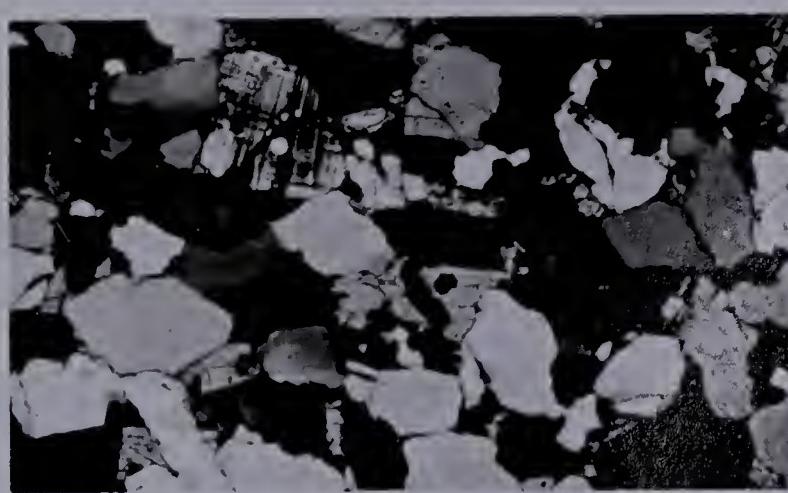
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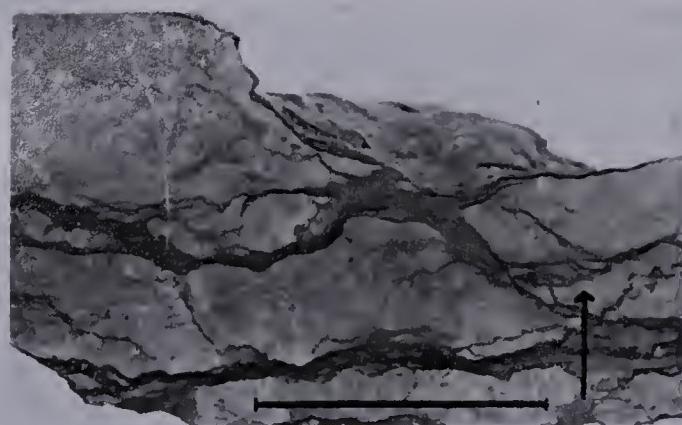
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PLATE 6



## PLATE 7

Figure 1. Calcareous, argillaceous, anhydritic laminated black shale of the basal Beaverhill Lake, pale grey to white laminae of dolomite and anhydrite crystals and silt to sand-sized quartz, thin section BCAC 10-23 # 2, X2.5; Homestead Ante Creek 10-23-65-24 W5M, depth 11,456 feet.

Figure 2. Skeletal micritic calcilutite containing sedimentary boudinage, left half of slide stained with alizarin red S, tendency of the skeletal material to become aligned around the 'boudins', at the base of the Dark Brown unit, thin section BCAC # 5, X2.5; Pan. Am. C-1 Ante Creek 4-4-65-24 W5M, depth 11,567 feet.

Figure 3. Coarsely crystalline dolomite rhombohedra pale grey to white, slide stained with alizarin red S, incorporation of calcite fragments within the dolomite structure, from the lower part of the Dark Brown unit, thin section BCAC 10-23 # 5, X2.5; Homestead Ante Creek 10-23-65-24 W5M, depth 11,435 feet.

Figure 4. Fine grained pelletal calcarenite (pellsparite) with fragments of Amphipora and gastropods, left side of slide stained with alizarin red S, thin section BCAC 4-4 # 6, X2.5; Pan. Am. C-1 Ante Creek 4-4-65-24 W5M, depth 11,598 feet.



Figure 5. Fine to medium grained calcarenite composed of pellets and intraclasts cemented by sparry calcite, under crossed-nicols, thin section BCAC 10-25 # 10, X10; Pan.Am.B-8 Ante Creek 10-25-65-24 W5M, depth 11,340 feet.

Figure 6. Very fine grained calcarenite grading into a micritic mud with poorly defined pellets and intraclasts, blebs of sparry calcite of secondary origin, inclusions of micrite in the spar, thin section BCAC 10-23 # 12, X25; Homestead Ante Creek 10-23-65-24 W5M, depth 11,381 feet.

Figure 7. Fine grained calcarenitic matrix stained red with alizarin red S (dark grey), contains well-formed rhombohedra of secondary dolomite (white to medium grey), Amphipora fragment with a framework of calcite and vacuities filled by secondary dolomite, thin section BCAC 4-8 # 12 X10; Pan. Am. D-1 Ante Creek 4-8-65-23 W5M, depth 11,306 feet.

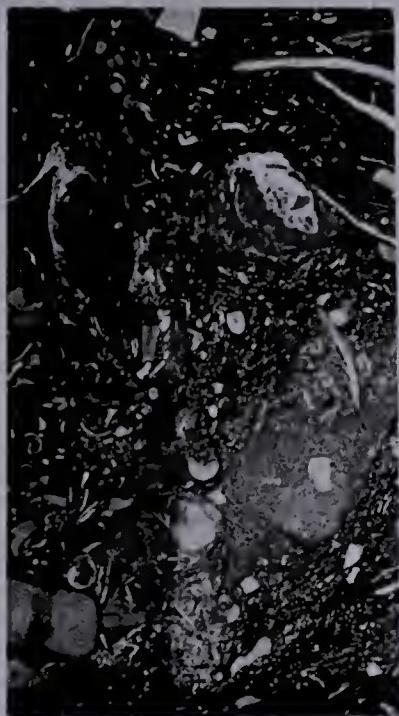
Figure 8. Large-amplitude stylolites filled by bituminous material and containing dolomite rhombohedra, in lower part of the Light Brown unit, thin section BCAC 4-15 # 3, X10; Atlantic Ante Creek 4-15-65-24 W5M, depth 11,511 feet.

Figure 9. Oolite band in black calcareous anhydritic laminar shale of the basal Beaverhill Lake, black rings on some oolites are pyritic, white material is sparry calcite, thin section BCAC 10-25 # 4, X2.5; Pan.Am.B-8 Ante Creek 10-25-65-24 W5M, depth 11,378 feet.

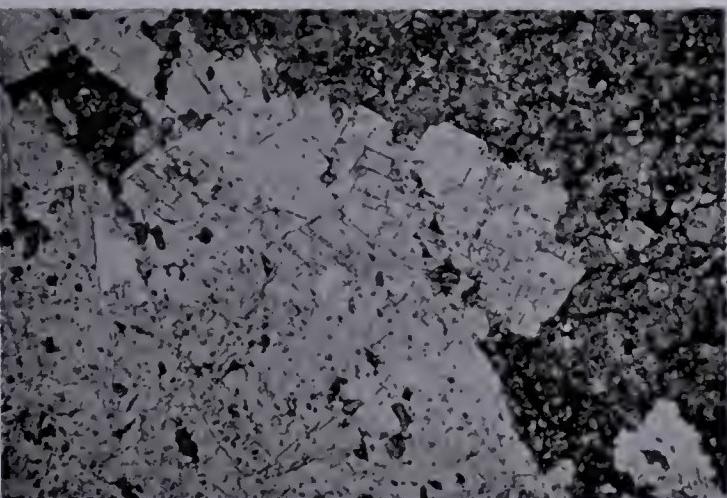




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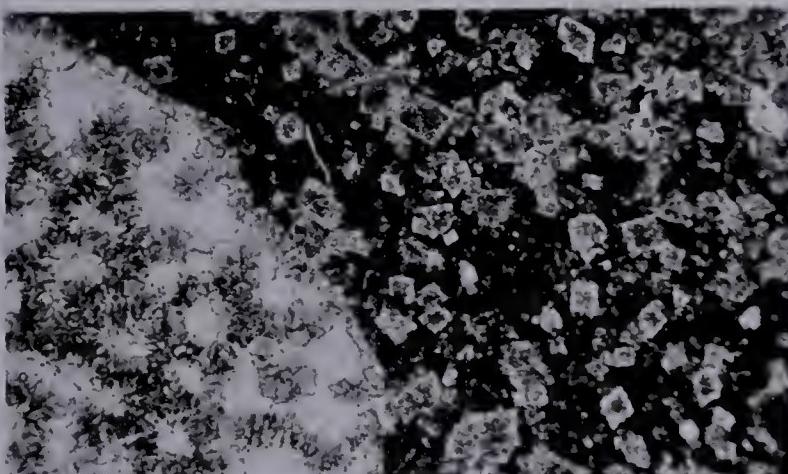
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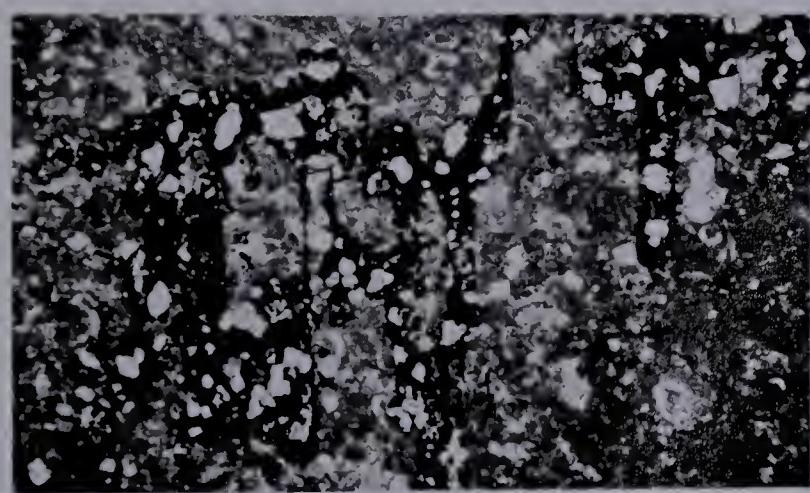
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PLATE 7



## APPENDIX I

## ANALYSIS OF ORGANISMS IN THE ANTE CREEK REEF

STROMATOPOROIDS (EXCLUDING AMPHIPOROIDS)

## MASSIVE STROMATOPOROIDS

Shape and Size: mainly hemispherical to irregular-shaped with undulatory upper surfaces, occasionally grading into digitate and bulbous coenosteal forms, may be encrusting and initially tend to acquire the general shape of the object being encrusted.

About 2 to 12 cm. across, averaging 6 cm. across for whole coenostea. (Plate 1, Figures 1 to 8 and Plate 2, Figures 1 to 4).

## Assigned Taxa:

Atelodictyon, Ferestromatopora, Parallelopora, Trupetostroma.

Lithologic Association: in situ massive stromatoporoids embedded in coarse micrite grading into calcarenite consisting of vague pellet and intraclast outlines, and skeletal fragments. Varying concentrations of bituminous-argillaceous material, sparry calcite and sucrosic dolomite are evident in the sedimentary matrix. Both primary and secondary porosity may be observed within particular specimens. Fragments interpreted as massive stromatoporoid material are embedded in lime muds with high concentrations of bituminous-argillaceous material, ostracods and Amphipora in the Dark Brown unit. These are interpreted as



having been transported to a quiet-water site of deposition.

Faunal Association: only minor occurrences of tabular and digitate stromatoporoids in the reef-edge facies where massive forms are most highly concentrated. Amphipora are only rarely present with massive stromatoporoids (Figure 7). Bulbous stromatoporoids as well as a variety of transported organisms such as brachiopods, crinoid ossicles, ostracods and coral fragments are associated with the massive type.

Position in the Ante Creek Reef: in situ massive stromatoporoids are abundant on the reef-edge or reef-front and in the main body of the reef. Some fine transported fragments occur in the fore-reef and lagoon-edge sediments (Figure 7). Massive stromatoporoids tend to be most profuse where the argillaceous content of the sediment (probably indicative of turbid conditions) is low, as in the Light Brown unit. There are massive stromatoporoid concentrations on the reef-edge which correspond with the turbulent zones of interpreted reentrant channels.

Interpreted Environment: highly turbulent, shallow, aerated water containing a high concentration of nutrients and relatively devoid of turbidity; similar to the position of massive coral types in modern reefs.

#### TABULAR STROMATOPOROIDS

Shape and Size: tend to be thin in the vertical dimension and



extensive in the lateral dimensions. Usually the laminations are prominent and may be horizontal to strongly undulatory. In certain specimens the upper surface tends to grade into digitate types; may be encrusting on flat surfaces and are sometimes termed 'pancake' stromatoporoids.

Tabular stromatoporoids are found from 2 mm. to 5 cm. in thickness and 5 cm. to greater than 9 cm. in lateral extent (Plate 2, Figures 5 to 7 and Plate 3, Figures 1 to 3). The small diameter of the core renders the differentiation between large laminar and massive stromatoporoids subjective.

Assigned Taxa:

Clathrocoilona, Stromatopora, Trupetostroma.

Lithologic Association: difficult to determine if in situ.

Most specimens show little wear and are commonly embedded in a matrix of coarse calcilutite grading into fine to medium calcarenite containing high percentages of bituminous-argillaceous material in the Dark Brown unit and low quantities in the Light Brown unit. Tabular stromatoporoids are commonly embedded in a matrix of recrystallized calcite and varying amounts of sucrosic dolomite in the Light Brown unit. There is a high concentration of fragmented tabular stromatoporoids in the base of the Dark Brown unit immediately above the interval containing sedimentary boudinage. At this horizon tabular



stromatoporoids are associated with skeletal fragments greater than 2 mm. in size. Also, there are some occurrences of tabular stromatoporoids in the upper part of Light Brown bioherm where the matrix contains moderate porosity. The coenostea tend to be outlined by stylolitic surfaces of small amplitude and appear to be more common in sediments of high argillaceous content than are the massive, bulbous or digitate stromatoporoids.

Faunal Association: found in many cases with in situ massive and digitate stromatoporoids. Fragmented tabular stromatoporoids occur with crinoid ossicles, disarticulated brachiopods and fragments of massive and digitate stromatoporoids. Ostracods are more abundant with in-place tabular stromatoporoids than with massive or bulbous types. Tabular stromatoporoids are common with whole and fragmented gastropods as well as in situ and transported thamnoporoid and solitary rugose corals.

Position in the Ante Creek Reef: fragmental tabular stromatoporoids compose up to 25 percent of a laterally persistant interval at the base of the Dark Brown unit. In situ types are scattered at intervals throughout the reef, although distribution tends to fit the reentrant channel pattern both vertically and laterally. Tabular stromatoporoids are common in the fore-reef, reef-edge, lagoon-edge deposits and at the base of, and along the sides of interpreted reentrant channels, their location being a function of turbulence.



Interpreted Environments: moderate to low turbulence, shallow to moderately deep-water hence their presence on the reef-front. The tabular types were able to withstand more turbid waters than digitate or bulbous forms.

#### DIGITATE STROMATOPOROIDS

Shape and Size: includes dendroid or finger-like forms, found as portions of single columns or as entire branching coenostea emerging from massive or tabular stromatoporoid surfaces. Digitate stromatoporoids are also gradational with certain bulbous types. The internal structure is compact to loose, often gradational into amphiporoid-type structures complete with central tubules.

Size highly variable, ranging from about 2 mm. to 1 cm. in diameter and from approximately 1 cm. to 5 cm. long in axial section (Plate 3, Figures 4 and 5).

Assigned Taxa: Stachyodes constulata, Stachyodes thomasclarki,  
Stachyodes verticillata, Trupetostroma.

Lithologic Association: in-place types are surrounded by fine to coarse micritic muds and fine calcarenitic limestones and are most common in the limestones of the Light Brown unit containing sparry calcite and sucrosic dolomite. The degree of intergranular and interskeletal porosity associated with the digitate stromatoporoids is highly variable in the Light Brown unit and low in the Dark Brown unit. Intraskeletal porosity is best developed in the



digitate stromatoporoids distributed through-out the upper part of the bioherm. In certain intervals, in situ and fragmented types are embedded in a matrix of pellets and calcispheres. Fragmented digitate stromatoporoids are associated mainly with medium to coarse calcilutite and fine calcirudite.

Faunal Association: Figure 7 illustrates that the distribution of digitate stromatoporoids roughly parallels that of the bulbous and massive forms and coincides with the Amphipora distribution to a minor extent. Digitate forms may grow from the upper surfaces of tabular or massive stromatoporoids and are associated with in-place tabulate and solitary rugose corals as well as crinoid ossicles. They are more abundant with tabular than with massive stromatoporoids and are found with whole ostracods and brachiopods. Digitate stromatoporoids are commonly found with solenoporacean and porostromate algae. However, digitate stroms tend to be abundant to the exclusion of most other in situ organisms.

Position in Ante Creek Reef: reef-front, lagoon-edge and back-reef deposits (see Figure 7).

Interpreted Environment: less turbulent water than the tabular stromatoporoids, low to moderate turbulence, shallow (back-reef) to deep (fore-reef).



## BULBOUS STROMATOPOROIDS

Shape and Size: subspherical to spherical with concentric laminae, some coenostea tending to be club-shaped having the bottom surface smaller in proportion to the top surface; the internal structure may be compact or porous.

Diameter from 1.5 to 9 cm., however, it is difficult to define the size and shape due to the small surface of the core being observed.

## Assigned Taxa:

Stromatopora, Trupetostroma.

Lithologic Association: commonly preserved in fine to coarse calcarenite and rarely in fine argillaceous micrite. The bulbous types occur in both the Dark and Light Brown units the lithologic matrix being often poorly to moderately porous and containing sucrosic dolomite.

Faunal Association: rare in most cores but found with in situ massive and digitate stromatoporoids and commonly with in-place tabular stromatoporoids. A very small percentage is associated with in situ Amphipora, massive stromatoporoid fragments, and disarticulated as well as whole ostracods and brachiopods. They are often associated with fragmental tabulate corals and whole gastropods.

Position in Ante Creek Reef: Figure 7 indicates that the bulbous types to predominate in the reef-core or the reef-ridge. Fragmentary material is found in the fore-reef deposits and to a minor degree, in the back-reef and lagoonal sediments.



Interpreted Environment: moderate to highly turbulent waters of the reef-ridge. Bulbous stromatoporoids were able to withstand more turbulence than digitate and tabular stromatoporoids but were structurally less robust than the massive forms.

### AMPHIPOROIDS

#### AMPHIPORA

Shape and Size: tabular, most specimens consist of a central open tube surrounded by a thick wall of tissue containing meandering calcite-filled vacuities; found with the long axis horizontal and may or may not be current-oriented. No branching coenostea or any type of anchoring structures were found.

The tabular coenostea range from 0.5 to 5.0 mm. in diameter and up to 30 mm. in length with central tubules being proportional to the general coenosteal size (Plate 3, Figures 6 to 8 and Plate 4, Figures 1 and 2).

#### Assigned Taxa:

Amphipora angusta, Amphipora pervesiculata, Amphipora ramosa.

Lithologic Association: in situ Amphipora in fine to coarse micritic muds and fine calcarenite with moderate to high bituminous-argillaceous content. At certain horizons in the Light Brown unit the calcarenitic matrix enveloping the Amphipora is completely recrystallized and



dolomitized, but the dense calcite within the coenosteum of the Amphipora is unaltered (Plate 4, Figure 2). Amphipora is completely leached out in certain thin facies. Amphipora of small diameter is confined to the Dark Brown unit, whereas the Amphipora of the Light Brown unit is of a larger diameter. Where Amphipora fragments are embedded in a calcarenitic limestone matrix, current sorting and abrasion of the outer rim of the coenosteum suggests transportation.

Faunal Association: abundant to the exclusion of most other organisms. They are commonly found with small quantities of tabular, massive, and digitate stromatoporoids. Whole ostracods are associated with in-place amphiporoids. Relatively undisturbed porostromate algae are common with Amphipora in micritic, laminated argillaceous limestones. Amphipora tends to be found with in situ digitate stromatoporoids to a greater extent than with massive or tabular forms.

Position in Ante Creek Reef: scattered at intervals through the reef and related to the quiet-water restricted stages of reentrant channel development. Amphipora increases in abundance from the east side of the reef to the west. In-place Amphipora occupies lagoonal and lagoon-edge deposits whereas the fragmental coenostea are located all over the reef.



Interpreted Environment: quiet water, warm, higher-than-normal salinity. Amphipora preferred the (turbid) environment of the lagoon.

#### EURYAMPHIPORA

Shape and Size: laterally expanded type of Amphipora having a very thin vertical dimension and extensive lateral dimensions. The observed specimens are oriented with flat surfaces horizontal.

Coenostea from 1 to 5 mm. in thickness and from about 5 mm. to greater than 9 cm. in diameter (Plate 4, Figure 3).

Lithologic Association: similar to that of Amphipora.

Euryamphipora is commonly embedded in coarse calcilutite with moderate to high concentrations of bituminous-argillaceous material. All samples appear to be in situ and are associated only to a minor extent with skeletal calcarenite.

Faunal Association: Euryamphipora occurs with Amphipora and in-place algal material e.g. porostromate and solenop-oracean algae, but is associated to a greater extent with massive, bulbous and digitate stromatoporoids.

Position in Ante Creek Reef: the samples collected were from the upper portion of the Dark Brown unit in Pan. Am. B-8 Ante Creek 10-25-65-24 W5M, Homestead Ante Creek 10-23-65-24 W5M, and Pan. Am. B-5 Ante Creek 10-27-65-24 W5M. In these wells Euryamphipora is massive, tabular and digitate



stromatoporoids as is the Amphipora, indicating a preference for the back-reef and lagoon-edge.

Interpreted Environment: quiet to slightly turbulent water and a preference for a less turbid environment than Amphipora.

### ALGAE

#### SOLENOPORACEAN ALGAE

Shape and size: commonly branching botryoidal to subspherical growths. The entire colony is concentrically laminate, with an internal structure of cells rectangular to hexagonal in cross-section, uniform in size, and separated by thick cell walls.

From 2 mm. to 1 cm. in diameter with cells averaging 0.1 mm. in cross-section (Plate 4, Figures 4 to 6).

#### Assigned Taxa:

Parachaetetes, Cuneiphycus?

Lithologic Association: in coarse calcilutite limestone as well as fine to medium calcarenite which typically contains sparry calcite cement and/or discrete blebs. The associated calcarenite is commonly in the form of pell-sparite. There is very little abrasion or fragmentation of the samples suggesting in situ growth. Solenoporacean algae prefer limestones of the Light Brown unit with moderate to low argillaceous content.

Faunal Association: A large percentage of solenoporacean algae



occurs with in-place Amphipora and digitate and massive stromatoporoids. It is associated to a lesser degree with tabular and bulbous stromatoporoids, brachiopods and porostromate as well as spongiostromate algae. Digitate stromatoporoids appear to be the most abundant co-inhabitators.

Position in Ante Creek Reef: greatest concentration in the upper half of Arco Ante Creek 10-6-65-23 W5M in the Light Brown unit. There are occurrences of sorenoporacean algae in the upper facies of the Dark Brown unit in Pan. Am. B-2 Ante Creek 4-25-65-24 W5M. This algal type is abundant in the reef-ridge to reef-edge facies located on the south end of the reef.

Interpreted Environment: moderate to low turbulence. The strong framework suggests the ability of the organisms to withstand moderate turbulence. Solenoporacean algae appear to have preferred shallow water of less than 30 fathoms (Brown, 1963, Page 180).

#### POROSTROMATE ALGAE

Shape and Size: simple open-ended, thin-walled, inter-twining tubes having no partitions, occasionally constricted at regular intervals and forming a chain-like structure with no external ornamentation. The tubes have varying diameters and lengths (Plate 4, Figures 7 and 8).

Diameter about 0.05 - 1.5 mm. on an average with some up to 0.6 mm. in diameter.

#### Assigned Taxa:



Girvanella.

Lithologic Association: in fine calcarenite to fine calcilutite limestones commonly with significant quantities of sparry calcite in the form of blebs or cement. Porostromate algae tends to be most abundant in the upper strata of the Dark Brown unit where the argillaceous-bituminous content is moderate to high. It is common in dense fine grained limestones which have little or no porosity, and which contain finely disseminated flakes of pyrite.

Faunal Association: most numerous with Amphipora, calcispheres, ostracods and occasionally brachiopod and coral fragments. Some porostromate algae is associated with digitate stromatoporoids, but is rarely found in situ with massive and tabular stromatoporoids.

Position in Ante Creek Reef: in lagoonal facies initiated by reentrant channels. Porostromate algae is concentrated to a large extent in the upper parts of the Dark Brown unit; however, is scattered laterally throughout the reef complex.

Interpreted Environment: very shallow, quiet, greater than normal salinity suggested from the presence of in situ ostracods.

## SPONGIOSTROMATE ALGAE

Shape and Size: subspherical to spherical coatings around nuclei of shell fragments forming oncolites. The internal structure of the spongiostromate algae is granular with concentric irregular layers of dark and light calcite



giving the impression of alternating compact and loose laminae respectively. This algal type also forms thin coatings on fragments of any size or shape, often acquiring the shape of the object encrusted (Plate 5, Figures 1 and 2).

Oncolites have an average range in diameter from about 8 mm. to 4 cm. whereas the laterally extensive encrusting types produce structures up to 5 mm. thick.

Assigned Taxa:

Spongiostroma?

Lithologic Association: in coarse calcilutite to coarse calcirudite limestone with varying amounts of sparry calcite as cement and blebs. Usually there is a trace of finely disseminated pyrite flakes present as well. This algal type is associated with intraclasts and pellets as well as abraded organic fragments.

Faunal Association: found with a wide range of fauna from massive, tabular, digitate and bulbous stromatoporoids, to Amphipora, porostromate algae, ostracods and calcispheres; commonly found coating brachiopod and gastropod fragments.

Position in Ante Creek Reef: scattered throughout the Dark and Light Brown units in on-reef and fore-reef locations, not numerous in the reef as a whole but locally abundant in thin beds.

Interpreted Environment: development in the turbulent zones is suggested by the shape and concentric nature of layers of the tissue. Oncolites were often carried down off the



turbulent zones of reef to the quiet-water environments where they became embedded in the fine muds.

## CORALS

### TABULATE CORALS

Shape and Size: thamnoporoid types tend to be branching, selected samples being difficult to distinguish from Stachyodes and Amphipora. The tubular corallites grow upward and outward (Plate 5, Figures 4 and 6).

Branching forms have diameters from 4 mm. to 1 cm. and lengths up to 5 cm., whereas the massive types have average diameters of 2 to 3 cm.

#### Assigned Taxa:

Thamnopora.

Lithologic Association: in fine to medium-grained calcarenites grading into calcilutites with varying amounts of sparry calcite cement and blebs, intraskeletal vacuities usually lined with sparry calcite.

Faunal Association: associated with a large variety of organisms including massive, digitate and bulbous stromatoporoids, Amphipora, brachiopods and crinoids. In-place samples tend to be common with massive and digitate stromatoporoids and Amphipora.

Position in Ante Creek Reef: found throughout the Light Brown unit in minor percentages. Tabulate corals are present in the Dark Brown unit in only one well, Pan. Am. D-1



Ante Creek 4-8-65-23 W5M. They tend to inhabit the fore-reef deposits, although fragments are present in the shallow lagoonal sediments of the reentrant channels, their frequency increasing toward the south end of the reef.

Interpreted Environment: moderately deep, moderately turbulent to quiet water of normal salinity. Specimens found in the lagoonal facies exhibit evidence of transportation.

#### SOLITARY RUGOSE CORALS

Shape and Size: horn-shaped with circular cross-sections, internal structure consisting of well-developed septae and dissepiments especially in the digonophyllids. Coral internal structure is usually white to buff in color (Plate 5, Figure 5). They range from 1 to 4 cm. in diameter and are of indeterminate length.

#### Assigned Taxa:

Alaiophyllum mackenziense, Digonophyllum?

Lithologic Association: embedded in fine to coarse calcarenitic limestones often containing sparry calcite cement. The interior structure of the coral is composed of white calcite, whereas the original interior vacuities of the skeleton are usually filled with sparry calcite. They are commonly found in zones of moderate to high porosity and dolomitization in the Light Brown unit.

Faunal Association: Solitary rugose corals are associated largely with tabular and digitate stromatoporoids and to a lesser



degree with massive, bulbous and amphiporoid stromatoporoids.

Where solitary rugose corals and Amphipora are found together they both bear evidence of transportation.

Position in Ante Creek Reef: in both the Dark and Light Brown units and scattered throughout the fore-reef, and back-reef deposits. In situ individuals are absent in the lagoonal facies.

Interpreted Environment: shallow to moderately deep water of moderate turbulence. Although some samples are found in the lagoonal deposits, they show evidence of transportation.

#### BRACHIOPODS

Shape and Size: sub-pentagonal to semi-circular shape with pedicle valve nearly flat and the brachial valve convex, ribs on the outer surface from fine to coarse. (Plate 5, Figures 7 and 8). The samples identified as Cranaena sp. are ovoid in circumference and smooth-shelled.

Width from 2 mm. to 2 cm. and length from 3 mm. to 2.5 cm., thickness being 2 mm. to 1.5 cm.

#### Assigned Taxa:

Atrypa cf. albertensis, Atrypa cf. deflecta, Atrypa cf. multicostellata, Cranaena sp.?

Lithologic Association: in calcilutite limestones and calcilutite grading into fine calcarenite. Brachiopods are embedded in dark brown and black calcilutite with high concentrations of bituminous-argillaceous material in the Dark Brown unit.



Brachiopods occur in the pale brown to buff calcarenite of the Light Brown unit. In the latter case, the matrix has from low to high porosity and from low to high concentrations of sucrosic dolomite.

Faunal Association: commonly found with crinoids, gastropods, ostracods, tabular stromatoporoids and spongiostromacean algae and to a lesser extent with digitate and massive stromatoporoids and porostromate algae. Brachiopods are rarely associated with Amphipora, both being fragmentary.

Position in Ante Creek Reef: heavily concentrated in three laterally consistent, thin units e.g. in Pan. Am. B-5 Ante Creek 10-27-65-24 W5M at a depth of 11,487 feet in the Light Brown unit, and in Pan. Am. B-2 Ante Creek 4-25-65-24 W5M at a depth of 11,318 to 11,325 feet in the basal two members of the Dark Brown unit. Brachiopods tend to be located in the fore-reef and reef-edge deposits. The basal unit of the upper Beaverhill Lake calcareous shale contains thin intervals of which 25 percent is composed of brachiopod fragments.

Interpreted Environment: the frequency of association between brachiopods and crinoids, gastropods, ostracods and spongiostromate algae indicates a moderate to deep-water environment of medium turbulence, assuming that the crinoid and gastropod remains are in situ.



## CRINOIDS

Shape and Size: circular stem ossicles with a central canal and serrated upper and lower surfaces.

The diameter is from 1 to 7 mm. (Plate 6, Figures 1 and 4 and Plate 7, Figure 2).

Lithologic Association: in micritic to fine calcarenitic limestones containing high concentrations of bituminous-argillaceous material.

Faunal Association: occur with brachiopods, ostracods, gastropods, spongiostromate algae and tabular as well as digitate stromatoporoids. Occur rarely with massive stromatoporoids.

Position in Ante Creek Reef: There are three prominent locations of crinoid ossicles in the reef: a laterally persistent basal interval in the Dark Brown unit, a zone in the middle of the Light Brown unit and one at the base of the upper Beaverhill Lake (Figures 9 and 10). Crinoid ossicles occur on the fore-reef slope and in the basinal sediments.

Interpreted Environment: moderately deep water of moderate to low turbulence.

## OSTRACODS

Shape and Size: flat-ovoid in cross-section to ovoid and subspherical in vertical section. The external surface of the valves are smooth, characteristic of the Leperditia type (Plate 6, Figure 2).

1 mm. to 3 mm. in diameter; several intervals where there



are fragments of what appear to be ostracod valves less than 1 mm. in size; the writer assumes these to be either small adults or juveniles.

Lithologic Association: whole valves are embedded in calcilutite with a moderate to high bituminous-argillaceous content, whereas the disarticulated and fragmented valves occur in calcilutite which grades into fine calcarenite.

Faunal Association: Common with Amphipora, porostromate algae, brachiopods, gastropods, tabular stromatoporoids and to a minor degree with digitate and massive stromatoporoids.

Position in Ante Creek Reef: common in the basal beds of the upper Beaverhill Lake and locally abundant at intervals throughout the Dark Brown unit. Ostracods are scattered in concentrated bands in the Light Brown unit, but are minor contributors to the sediments of the reef as a whole.

Interpreted Environment: tended to inhabit the quiet, muddy waters of normal to high salinity, although a few whole samples in this thesis were found associated with digitate, tabular and massive stromatoporoids as well as gastropods and brachiopods. It is the writer's opinion that those specimens were not necessarily transported but may have inhabited the same muddy bottoms and turbid waters of normal marine salinity.

## MOLLUSCS

### GASTROPODS

Shape and Size: helical, low to high-spired with whorls of the



largest diameter at the bottom and diminishing in size upward. Maximum whorl diameter from 5 mm. to 3 cm. (Plate 6, Figure 3).

Lithologic Association: in coarse calcarenite and micritic calcilutite limestones. Gastropods are more common in limestones with a high bituminous-argillaceous content although there is one interval containing gastropods in the Light Brown unit. The initial internal cavities are filled by micrite mud or by sparry calcite.

Faunal Association: solitary corals, crinoid ossicles, ostracods, brachiopods, spongiostromate algae, tabular and to a small extent digitate, massive and amphiporoid stromatoporoids.

Position in Ante Creek Reef: rare throughout the reef; found mainly in reef-front to off-reef basinal sediments and occasionally in shallow sediments. Gastropods are found at three main horizons in the reef: at the base of the Dark Brown unit, half-way through the Light Brown unit and at the base of the upper Beaverhill Lake argillaceous limestones.

Interpreted Environment: shallow to deep water, turbid muddy bottom, quiet to moderately turbulent. Gastropods cover a wide range of environments.

#### PELECYPODS

Only one pelecypod specimen was encountered. It is located in Pan. Am. B-8 Ante Creek 10-25-65-24 W5M at 11,355 feet. It is roughly 5 by 7 cm. in size, is embedded in dense, dark brown micritic



limestone and belongs to the genus Megalodon. The shell structure is filled with coarsely crystalline sparry calcite. This may be similar to the megalodont zone described by Klovan (1964) on the fore-reef slope of the Redwater Reef.

#### MICROFAUNA (EXCLUDING OSTRACODS)

##### FORAMINIFERA

The writer attempted to extract foraminifera at several horizons but was unsuccessful. The single specimen encountered was located at 11,586 feet in Pan. Am. B-5 Ante Creek 10-27-65-24 W5M. Little abrasion is displayed by the sample and it is assumed to be in situ. However, it may have drifted into the quiet, muddy environment as suggested by the enclosing bituminous-argillaceous micrite. The sample appears to be biserial changing to uniserial in an upward direction and has a calcareous test. It is probably a pleurostomellid-type (Plate 6, Figure 5).

##### CALCISPHERES

The writer includes under this heading all thick-walled spherical bodies having diameters averaging 0.2 mm. in size and scattered throughout the micritic lagoonal facies of the reef. An algal origin has been suggested for these objects by several authors notably Murray (1966, pages 23 and 24).

##### AFFINITIES UNCERTAIN

An organism of questionable origin occurs commonly throughout the reef (Plate 6, Figure 6). It is common in Pan. Am. B-8 Ante Creek at 11,320 feet and Pan. Am. B-1 Ante Creek 10-13-65-24 W5M, at 11,394



feet. Both locations are within the Dark Brown unit. Leavitt (Plate 13, Figure 40) identified this as Tikhinella sp.

However, the writer does not accept a foraminiferal origin because the septa between the chambers are too thick. The chambers are too rectangular and the outer walls are too straight and parallel. This organism could be a form of Tentaculites, however, it is larger than any of the samples collected and/or observed in the other reefs of Swan Hills age.





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